Editor's Note

South Africa has several features that it shares with countries such as India and China: it is poor but growing; it faces rising demand for energy and in particular electricity; and it is naturally endowed with large coal supplies that dominate its power generation mix.

The dominance of King Coal in the United States and parts of Europe has given rise to an interest in carbon capture and storage (CCS)—the capture of CO_2 emissions from power plants or industrial processes and its long-term disposal in geological formations. For countries looking to make deep cuts in emissions without fundamental changes to their energy systems, it offers an important technology option. Often this attractiveness to Annex I countries is assumed to mean that it will be equally appropriate in developing countries.

Here we reach one of the limitations of the SD-PAMs approach. True, the authors find that South Africa has a large potential for carbon storage (20 gigatons). But with the exception of a few installations (see below) these entail prohibitive costs. CCS brings few sustainable development benefits, and indeed may work against sustainable development goals. If South African resources were to be diverted towards CCS it would increase the cost of power significantly, slowing the increase in electrification (and the provision of some free power to households) that is a central aim of government policy. Although CCS may reduce some pollution from coal use by encouraging the use of more modern coal plants, it will also increase total coal demand, with a corresponding increase in the life-cycle impacts of coal use. In short, there seems little chance of making this approach work in the absence of explicit mitigation commitments. These mitigation commitments would not need to be on the part of South Africa: it would be possible for donor countries to finance the future capture and storage of South African emissions. But the amounts of money involved would be a step change in the willingness to pay for GHG mitigation. And were this approach to be applied in much larger countries such as China and India, the cost would be far higher. Since other sustainable development goals are not being met, using traditional sources of funding such as official development assistance would not be appropriate.

So where does this leave us? First, there is potential for some relatively low-cost emission abatement with CCS from specific installations which are well-suited to the technology. These include mainly plants for gasifying coal for the production of liquid fuels and synthetic chemicals—installations that may represent 30 million tons of CO_2 per year that could be sequestered for around $20 per ton. This would not strictly be an SD-PAMs activity as it would be a "pure" mitigation measure, but is an important finding nonetheless. It is not impossible that in the future there will be sufficient international concern about runaway GHG emissions that developing countries, donor countries or both will find the resources needed to implement CCS in emerging economies. South Africa is a good example of an advanced developing country that may in time adopt CCS technologies, with or without international support, though it should be stressed that that time still looks far off. The authors identify a number of factors that mark important differences between developed and developing countries in the way that this implementation might take place, in particular in questions of safety standards and institutional capacity—though possibly South Africa is not a representative example of a developing country in this regard.

Nevertheless, the final conclusion is that, for the time being, CCS does not seems to support the central sustainable development aims of South Africa in a way that other options such as gas and renewable energy supplies may, and CCS may even conflict with national development goals. While the dominance of coal in South Africa, China, and India has led some commentators and policymakers to put their hopes in CCS, the particular circumstances of developing countries may make other options more realistic.

CHAPTER VI

Carbon Capture and Storage in South Africa

Stanford Mwakasonda ▪ Harald Winkler

1. INTRODUCTION

Some three-quarters of South Africa's primary energy supply and 93 percent of its electricity are derived from coal (NER, 2002; DME, 2003b). Even in more optimistic energy policy scenarios (De Villiers and others, 1999; EDRC, 2003; Banks & Schäffler, 2005), coal continues to provide for the majority of South Africa's energy needs over the next 20 to 30 years. Almost 80 percent of GHG emissions come from the energy sector—both supply and use—and most of these are in the form of carbon dioxide (Van der Merwe & Scholes, 1998; RSA, 2004).

Making South Africa's energy system more sustainable is a transition that will take decades. Making energy development in South Africa more sustainable will require attention to solutions that deal with CO_2 emissions from coal. Together, these factors mean that an evaluation of the sustainability of carbon capture and storage (CCS) technologies is an important element of climate policy.

1.1 Context: climate change and sustainable development in South Africa

South Africa's development objectives have been shaped deeply by Apartheid—a history of racial oppression and patterns of economic exploitation. Apartheid systematically underdeveloped black working-class communities and left a deep legacy of backlogs of basic services in rural and urban areas. A central driver for policy since 1994 has been the redress of the imbalance of Apartheid and the promotion of the socioeconomic development of poor communities. A core document capturing the major objectives is the Reconstruction and Development Programme (RDP). However, the imperatives of reconstruction and development have been in tension with a macroeconomic framework that emphasizes economic growth as the driver of development—the Growth, Employment and Redistribution (GEAR) strategy (2002). The main feature of the vision of GEAR was a competitive fast-growing economy that creates sufficient jobs for all work-seekers. To achieve the GEAR employment goal, a minimum growth rate of 3 percent per year would have to be met.

Many of the detailed socioeconomic development objectives were set in the African National Congress' RDP (ANC, 1994). It outlined job creation through public works and meeting a range of basic needs as key priorities. Quantified goals were set for delivery of basic services, including (a) building 300,000 housing units each year for the first five years (to address a housing backlog of some 2–3 million houses); (b) redistributing 30 percent of the land; (c) providing 25 liters of water per person per day; and (d) providing electricity to 250,000 households per year (this target has actually been exceeded) (Borchers et al., 2001).

Relative to other sectors, the energy sector has performed well in meeting such targets. Significant progress has been made in extending access to electricity in particular, although affordability and productive use remain issues. Yet more remains to be done, and the challenge of delivering energy in a sustainable manner remains.

Energy makes a critical contribution to sustainable development by providing households with access to affordable energy services and contributing to economic development. However, it is important to manage the environmental impacts of energy supply and use. South Africa's national climate change response strategy, approved by the Cabinet in October 2004, is built around sustainable development; its point of departure is the achievement of national and sustainable development objectives while simultaneously responding to climate change (DEAT, 2004). Any technological option, including CCS, needs to fit within the broader South African approach to climate policy.

1.2 CCS and South Africa's commitments under UNFCCC

South Africa's climate policy is rooted in a firm commitment to the multilateral process under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. South Africa is a signatory to both the UNFCCC and the Protocol.[1]

Being a signatory to the UNFCCC, South Africa has a general commitment to "implement … measures to mitigate climate change" (UNFCCC, 1992: Article 4.1b). As a non-Annex I country, however, it does not have a *quantified* emissions limitation or reduction target under the Kyoto Protocol. Nonetheless, the climate change response strategy recognizes that the country can benefit from moving to a cleaner development path. For example, one of the major objectives of the White Paper on Energy Policy is to secure the nation's energy supply through diversity (DME, 1998). The Clean Development Mechanism (CDM) and other climate funding opportunities are seen as key in driving this development. Domestic policy has also recently resulted in a voluntary renewable energy target of 10,000 GWh by 2013 (DME, 2003c).

At least in principle, CCS offers an option to use coal with lower GHG emissions than under a business-as-usual approach. Initial research into the potential of CCS (Engelbrecht et al., 2004) has focused on Sasol, the chemicals and synthetic fuels producing company, and the existence of pure CO_2 streams in the coal-to-liquids process, as the most promising option for capture. The potential to generate credits under the CDM has been highlighted: "At $10 per ton [of carbon CDM credit price], the sequestration of this 30 million tons per year could be worth $300 million per year" (Surridge, 2004). This assumes that suitable storage sites can be found at reasonable cost in environmentally acceptable conditions. A further question is how long this carbon storage avenue will exist, since Sasol is switching its feedstock from coal to gas piped from Mozambique (Poggiolini, 2001; ECON, 2004). The key sources of CO_2 in South Africa are shown in Table 1.

Any proposal to capture CO_2 for storage must take into account the fact that a number of sources—for instance, those involving transportation—are unlikely to be suited to the capture of their emissions, because they are generally too distributed. Table 1 provides the breakdown of sources of carbon dioxide in South Africa. Based on the source category technologies amenable to capture processes, the hypothetical maximum amount of capturable carbon dioxide in South Africa is about 212 Mt/a, or 58 percent of all anthropogenic CO_2 released (Lloyd, 2004). The distribution of sources is discussed further in section 3.

1.3 Purpose of this chapter

South Africa, a developing country with an energy economy dominated by coal, has potential for carbon capture and storage (CCS). Given its strong commitment to sustainable development, the country may want to understand the implications of this climate change mitigation option for local development—in its economic, social, and environmental dimensions.

South Africa is expected to remain dependent on coal for decades to come (DME, 2003a), but will increasingly be challenged to contribute to the global effort of climate change mitigation, or reducing emissions of greenhouse gases (GHGs). In this context, CCS might be attractive to South Africa's minerals and energy sector, with its high reliance on coal and the existence of pure carbon dioxide (CO_2) streams in the coal-to-liquid fuel process. Its "minerals-energy complex" (Fine & Rustomjee, 1996) has already become involved in exploring CCS[2] through participation in the Carbon Sequestration Leadership Forum (CSLF) and the Intergovernmental Panel on Climate Change (IPCC) processes. This report seeks to understand the broader implications of CCS for sustainable development, and how it compares to alternatives: CCS might make sense as pure climate policy, but how does CCS line up alongside other mitigation options with respect to development?

The report considers the political, technological, and institutional prerequisites for making CCS work in a developing country, and the discussion of its potential to become an important component of a coherent climate strategy. Given that climate policy has low priority relative to development for basic human needs, the report tries to address the question of whether (and to what extent) CCS can contribute to *local* sustainable development.

Research on CCS has been receiving much attention recently; for example, the IPCC is preparing a special report on the subject. While there has been increasing interest in CCS in the developed world, its only serious consideration in developing countries has been in locations where international energy companies are active.

Table 1. Sources of Carbon Dioxide in South Africa, 1990

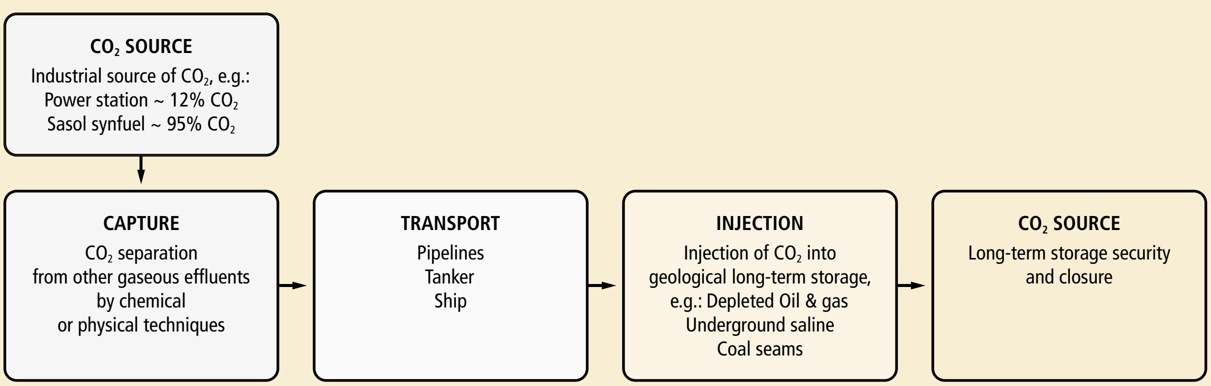
	CO_2, Mt/a		CO_2, Mt/a
Likely to be capturable		**Unlikely to be capturable**	
Electricity generation	137	Waste	9
Industry	24	Agriculture	41
Other energy production	26	Fugitive	36
Manufacturing	26	Transport	34
		Heat production	32
Total capturable	**212**	**Total non-capturable**	**152**
Total Emissions (capturable & non-capturable)	**364 Mt/a**		

Source: Lloyd (2004), drawing on Engelbrecht et al. (2004)

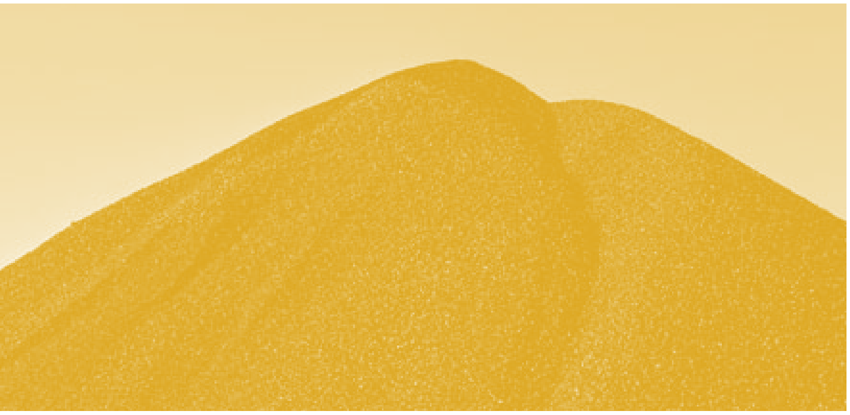
2. WHAT IS CARBON CAPTURE AND STORAGE

Carbon capture and storage is a technology envisaged to mitigate GHG emissions by producing a concentrated stream of CO_2 that can be transported to a storage site. It is most likely to be applicable in large centralized sources, including power plants, other energy industries (oil refineries, synthetic fuel plants), and fossil-fuel-intensive industries (iron & steel, cement, chemicals). Four stages of the process are identified in Figure 1. After initial capture of the gas, the CO_2 needs to be transported to a suitable storage site for injection. Monitoring CO_2 after injecting it into a storage area (geological formations) is important to ensure permanent storage and safety for human health and the environment.

Figure 1. Process of Carbon Capture and Storage



Source: Surridge (2004)



2.1 Carbon capture

In some existing processes, CO_2 is separated from other gases routinely, such as in natural gas processing and ammonia production (Kohl & Nielsen, 1997). In South Africa, Sasol produces pure streams of CO_2 in the process of gasifying coal.[3] These streams of CO_2 can be captured at minimal additional cost, although they still need to be transported and stored appropriately.

Alternatively, capture of CO_2 will depend on the combustion technology. There are three classes of combustion technologies under consideration. First, the oxy-fuel combustion technology, in which a hydrocarbon or carbonaceous fuel is combusted in either pure oxygen or a mixture of pure oxygen and an inert gas rather than in air (which is 79 percent nitrogen) (Lloyd, 2004). The major drawback to oxy-fuel combustion is the cost of oxygen separation.

Secondly, separation can be carried out before combustion. Pre-combustion processing of the primary fuel in a shift reaction[4] could separate CO_2 and H_2, with the former stored and the latter used as fuel. South Africa's extensive experience with gasification and re-forming for both syngas and hydrogen production have given it an excellent knowledge base from which to contribute to pre-combustion technologies generally.

Thirdly, CO_2 can be captured using post-combustion technologies. In post-combustion technology, CO_2 is separated from flue gas after the fuel has been burned (IEA GHG, 2000). The best proven technique to separate the CO_2 from flue gas is to scrub it with mono-ethanol amine (MEA) solution (Engelbrecht et al., 2004). The disadvantages of post-combustion capture are that the equipment sizes are large due to the large flue gas volumes and the low CO_2 concentration in the flue gas (10–15 percent) (Engelbrecht et al., 2004). The energy requirements of CCS reduce the efficiency of power plants, imposing an "energy penalty" (Bolland & Undrum, 1999). International reviews suggest that the efficiency of pulverized coal declines from 46 percent to 33 percent for pulverized coal and from 56 percent to 47 percent for natural gas combined cycle power plants (Lloyd, 2004). In the South African case, therefore, the large Eskom (South Africa power utility) power stations, with units on the order of 600 MWe, would not be able to retrofit proven systems for post-combustion CO_2 capture (Lloyd, 2004).

2.2 Carbon storage

Once captured, CO_2 can be kept in storage areas such as geological formations. The CO_2 can be trapped physically below impermeable rock, dissolved or ionized in groundwater, retained in pore spaces, or adsorbed onto organic matter in coal and oil shale (Hitchon, 1996). All these forms of storage have long residence times (thousands to millions of years). Possible types of storage sites include depleted oil and gas fields and deep underground formations filled with saline water.

Existing technology required to inject carbon in deep geologic formations has been developed by the oil and gas exploration industry (Bajura, 2001). Projects specifically designed to store CO_2 have started to develop experience with storage for CCS specifically, although the scale is still small relative to the future requirements. Costs are variable and are location-specific (Knauss et al., 2001). Environmental concerns relate to the permanence of the storage and the health and safety implications of possible concentrated releases in the future. Criteria for site selection include the storage capacity (related to its porosity), permeability, any physical or hydrological barriers to CO_2 storage, and the stability of the geological formation.

Oceans can also be used for carbon dioxide storage by releasing CO_2 to the deeper ocean water layers, at least 1,000 meters below sea level. Ocean storage of CO_2 is made possible by the fact that the cold deep sea waters of the oceans are unsaturated with CO_2 and therefore have a significant potential to dissolve it. Ocean storage relies on the fact that below a certain depth, CO_2 becomes "supercritical," with liquid-like densities, and being less buoyant than water, will not rise (Gunter, 2001). However, slow turnover in the ocean's layers, even at great depths, means eventual release on the timescale of centuries.

3. THE POTENTIAL FOR CCS IN SOUTH AFRICA

A report (Engelbrecht et al., 2004) by the Council for Scientific and Industrial Research, CSIR, commissioned by the Department of Minerals and Energy, made a preliminary assessment regarding the potential for CO_2 sequestration in South Africa (Surridge, 2004). Unsurprisingly, the major potential for capture lies in the major point sources of CO_2 emissions—electricity generation, synfuels (Sasol), oil refineries, and energy-intensive industries such as iron and steel, nonferrous metals, pulp and paper, and cement (Engelbrecht et al., 2004).

3.1 The potential for carbon capture in South Africa's energy sector

This first scoping report identified the Sasol coal-to-liquids process as well-suited for CO_2 sequestration. In their coal gasification process, there are reportedly CO_2 streams of 90 to 98 percent purity, meaning that minimal capture is needed (only pressurizing). Since capture costs dominate the overall costs of CCS, this is a substantial advantage (see section 4.1). Slightly lower concentrations (80 to 90 percent) are reported at Mossel Bay (Engelbrecht et al., 2004), where PetroSA generates synthetic fuel from gas.

The other potentially large source is coal-fired electricity generation, which provides 93 percent of electricity supply (NER, 2002) through the publicly owned company Eskom. However, the flue gases contain much lower concentrations of CO_2 at 10-15 percent,[5] implying that the costs of capture will be significant. Coal provides some three-quarters of total primary energy supply (DME, 2002), and industry uses large amounts of coal as the other major energy carrier next to electricity.

The electricity sector contributes almost half (47.4 percent)[6] of CO_2 emissions in South Africa (Van der Merwe & Scholes, 1998; RSA, 2004). CO_2 emissions in South Africa are concentrated in the central industrial area.

3.2 Review of potential for geological and ocean storage

3.2.1 Geological storage

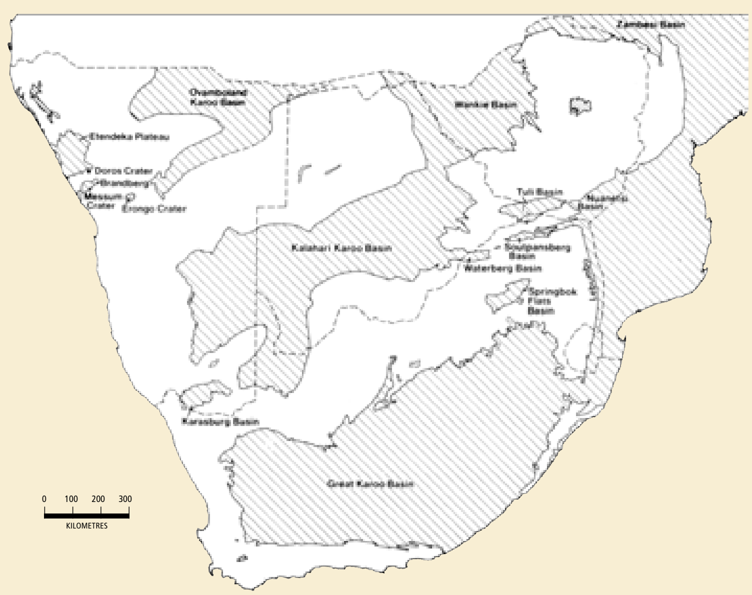
Geological sequestration of CO_2 involves the use of geological formations like depleted oil and gas reservoirs, abandoned gold mines, deep saline aquifers, or unminable coal seams. Such storage of CO_2 would involve injection into the formations after capturing it at source points. Geological gas and oil reservoirs can be ideal for CO_2 storage because the injected CO_2 can be used to restore the reservoir to its original pressure, thereby reducing the risk of possible collapse. Further, the natural sealing mechanism that retained the hydrocarbon in the first place offers a significant advantage in ensuring that the CO_2 does not escape to the surface. However, oil or gas development activities might be a potential source of risks due to reservoir fractures.

For South Africa, the potential for using depleted oil and gas fields for CO_2 storage is not significant because of the low prevalence of oil and gas activities in the country (Lloyd, 2004). In the CSIR study (Engelbrecht et al., 2004), the storage capacity of oil and gas fields in South Africa has been based on their current production rate of about 1.4 billion m^3/y. Discounting this figure by 50 percent after some allowances produces a CO_2 storage capacity of about 0.7 billion m^3/y (approximated at one million ton of CO_2 per year) at 80 bar pressure (Lloyd, 2004).

Abandoned coal and gold mines in South Africa offer another potential for CO_2 storage. Storage capacity of CO_2 in abandoned mines was based on production rates. Abandoned coal mines have previously been used as storage facilities for oil (Engelbrecht et al., 2004), but appeared to offer little CO_2 storage capacity. No figures were available when the CSIR study was conducted. For abandoned gold mines, assuming production of 390 tons of gold annually, 20 million m^3 of ore removed annually, and the number of exhausted gold mines available in South Africa, a yearly CO_2 storage figure of more than 10 million m^3 would be possible at 80 bars of pressure (Lloyd, 2004).

Another potential area of geological CO_2 storage in South Africa is deep saline reservoirs (Figure 2). The Karoo Supergroup Sediments offer the highest potential compared to other sediment zones in the country, which lack a trapping or sealing mechanism. Two major areas in the Karoo sediments are the Vryheid Formation and Katberg Formation. These two formations are relatively old and highly consolidated. The Vryheid formation has an estimated CO_2 storage capacity of 183,750 million m^3 (approximately 183,750 million tons at 80 bar pressure) (Engelbrecht et al., 2004). The CSIR study found,

Figure 2. Southern Africa's Geological Zones for CO_2 Storage



Source: Engelbrecht et al. (2004). Shaded areas are those suitable for CO_2 storage.

however, that "these sandstones are characterized by low porosity (3 to 5 percent) and poor permeability" (Engelbrecht et al., 2004). Making allowances for poor permeability of the sediments and other factors, a storage capacity figure of 18,375 million tons was estimated.

The Katberg Formation was estimated with a CO_2 potential storage capacity of 8 billion m^3. This figure was discounted to approximately 1.6 billion m^3 (1,600 million tons of CO_2 at 80 bar pressure) to allow for poor storage capacity as well as geological and other constraints.

The combined CO_2 storage capacity for the two formations, given the low porosity and permeability, comes to about 20Gt CO_2, sufficient to store virtually all the capturable CO_2 produced in the next 100 years (Lloyd, 2004).

For South Africa, it would probably be reasonable to assume a distance of about 250km between source and sink, although this would clearly depend on improved source-sink matching.

Ocean storage

Deep ocean storage is "nearly unlimited," but South African storage potential has not been quantified, nor has that that from ocean fertilization to increase the uptake of CO_2 (Engelbrecht et al., 2004). The CSIR study concluded that "deep ocean sequestration of CO_2 is potentially possible; however, environmental and legal consequences are poorly understood." In order to understand the potential of ocean storage of CO_2 in South Africa, one would need to study the seabed profile of submarine contours adjacent to major sources of CO_2.

Total theoretical CO_2 storage potential

Table 2 summarizes the theoretical potential geological and ocean storage for carbon dioxide sequestration in South Africa.

Table 2. Potential for Geological and Ocean CO_2 Storage in South Africa

Potential sink	Tonnage ($MtCO_2/y$)	Potential Storage Duration (years)	Comments
Oil and Gas reservoirs	1	Very long (millions of years)	There may be enhanced gas recovery
Gold mines	10 or more	Site specific	More study required
Vryheid Formation	18,373 million total	Very long (millions of years)	Relatively poor porosity and permeability, more study required
Katberg Formation	1,600 million total	Very long (millions of years)	Relatively poor porosity and permeability, more study required
Deep ocean (Atlantic and Indian)	Nearly unlimited	Several hundred years	Deep ocean ecosystems poorly understood; impacts of CO_2 a potential cause for concern

Source: Engelbrecht et al. (2004)

Table 2 shows that South Africa has potentially large geological storage, particularly in saline reservoirs. The potential for CO_2 sequestration in exhausted gas fields at Mossel Bay needs more study, also because it may enhance gas recovery. There is also a potential to use exhausted gold mines for CO_2 sequestration, but this area needs more study as mining activities might have reduced the sealing effect for carbon storage. On geological formation storage, it appears that the porosity and permeability is rather low, but the potential for CO_2 sequestration is large and therefore further study is required.

Ocean storage in the country is potentially large, but quantified estimates are unknown. Ocean storage also raises environmental and legal issues that have led to widespread opposition internationally, and to the suspension of some high-profile research activities.

4. CCS AND SUSTAINABLE DEVELOPMENT

CCS needs to be assessed against the various dimensions of sustainable development. The indicators used by the Designated National Authority for the CDM in South Africa are shown in Table 3. Sustainable development is defined in three dimensions—ecological, economic, and social. The ecological dimension considers impacts on local environmental quality, natural resource use, and impacts on ecosystems. Economics considers not only cost, foreign exchange, and local economic development, but also includes appropriate technology transfer. The detail of the social indicators reveals an emphasis on delivery of services at a local community level and the alleviation of poverty.

While no set of indicators is perfect, the indicators reflect the broad priorities of the RDP outlined in section 1.1. Not only are these particular indicators used operationally in mitigation projects in South Africa, but they were informed by some stakeholder consultation. In our analysis the implications of CCS for sustainable development are evaluated very simply, as positive, negative, or neutral. Key impacts have been highlighted in bold.

The key positive implications for CCS are the reduction of GHG emissions, making production cleaner, and introducing new technology. The need to import significant components of new technology (and the negative impact on foreign exchange requirements) offsets the latter benefit. Negative implications that stand out are the increased cost of energy and other services. The economic, social, and environmental implications of CCS are described in more detail in the following sections.

Table 3. Review of CCS and Sustainable Development in South Africa

Criterion	Indicator	Reference to CCS	Positive or negative contribution to local sustainable development
Ecological			
Impact on local environmental quality	• Will the project increase air pollution in the area?	No	**Positive**
	• Will the project increase water pollution in the area?	Possible	Negative
	• Will the project increase solid waste in the area?	No	Positive
	• Will the project have any other negative environmental impacts (such as noise, safety, property, value, visual impacts, traffic)?	Possible, in case of pipeline construction, abrupt leakage	Negative
Change in usage of natural resources	• Will the project reduce community access to resources?	No	Positive
	• Will the project increase the sustainability of usage of water, minerals, or other nonrenewable natural resources?	No	Negative
	• Will the project achieve more efficient resource utilization?	Not applicable	Neutral
Impacts on biodiversity and ecosystems	• Will the project result in a loss of local or regional biodiversity?	Possible	Negative
Economic			
Economic impacts	• Will the project substantially increase foreign exchange requirements?	Yes	**Negative**
	• Will the project have a negative impact on existing economic activity in the area?	Unlikely	Neutral
	• Will the project increase the cost of energy?	Yes	**Negative**
Appropriate technology transfer	• Will the project result in the introduction of appropriate technology into South Africa?	Yes	**Positive**
	• Will the project result in local skills development?	Yes	Positive
	• Will the project provide demonstration & replication potential?	Limited	Positive
	• Will the project incorporate cleaner production technology?	Yes	**Positive**
Social			
Alignment with national, provincial, and local development priorities	• Will the project undermine other government objectives?	No	Positive
	• Will the project increase the cost of other services?	Yes	**Negative**
	• Will the project result in relocation of communities?	Possible, in case of pipelines	Negative
	• Will the project provide infrastructure or essential services to the area (such as increased access to energy)?	No	Negative
	• Will the project complement other development objectives in the area?	No	Negative
	• Will the project contribute to a specific sectoral objective? Example: to increase access to renewable energy.	No	Negative
Social equity and poverty alleviation	• Will the project result in the creation of jobs? (provide details as above)	Possible, high skills	Positive
	• Will the project provide any social amenities to the community in which it is situated?	Unlikely	Neutral
	• Will the project contribute to the development of a previously underdeveloped area?	No	Negative

Source: Adapted from those published by the Designated National Authority, DME (2004). Key positive or negative impacts are highlighted in bold.

4.1 Economic

4.1.1 Comparing CCS to alternative mitigation options

Compared to alternative mitigation options, the initial costs for CCS storage technologies are likely to be high, with expectations of a decrease when they become more widespread and popular. This is the general trend for all new technologies. It has been argued that CCS, compared to most other mitigation or sequestration projects, does not offer other sustainable development benefits, apart from the reduction of GHGs in the atmosphere. The sustainable development aspect will be discussed in a later section.

CCS technology transfer elements become relevant to South Africa when considering the envisaged development of the natural gas industry. South Africa has small reserves of natural gas and coalbed methane—not enough to justify an extensive pipeline infrastructure. The existing pipeline system links Gauteng, Durban, and Secunda, where Sasol plants are located. An extensive pipeline infrastructure will be necessary to access gas fields in neighboring countries, including Angola, Namibia, and Mozambique. Angola has large gas fields; in the future, gas could be piped to South Africa from there. Since CO_2 transport by pipeline has similarities to that of natural gas, this is where the relevance of CCS technology transfer comes into play. Similarities include the need for pipeline construction that is not intrusive to communities, as well as issues like safety, efficiency of pipeline operations, and improving telecommunications and computer systems for monitoring and remote control of pipelines. Other areas include developing tools and technologies that detect areas of potential deterioration from dents, corrosion, metal loss, and pipeline cracks.

4.1.2 International cost estimates and first South African estimates

CCS would clearly impose additional costs for Eskom's generation of electricity or producing synfuel at Sasol. The other cost components relate to transport and storage costs. There have been few attempts to quantify monitoring costs in existing studies.

International cost estimates

With no local CCS experience, most of the studies are based on international experience. Table 4 shows increased costs of electricity in the United States. With post-combustion capture, the increase in electricity cost to capture CO_2 is 87 percent. For integrated gasification-combined-cycle (IGCC) plants with pre-combustion capture, the increase in electricity cost is 52 percent. For in-combustion capture, the cost increase is estimated at 34 percent. For South Africa, some initial indications of the cost *patterns* in South Africa emerge (Lloyd, 2004).

Costs of CCS in coal-to-liquids plant and industry

The lowest costs for capture are those where there are already high concentrations of carbon dioxide present. In the case of pure CO_2 streams, such as those available at Sasol's Secunda plant and PetroSA, there are only compression costs. Since capture costs typically dominate total costs of CCS, these options are being investigated for their potential (Surridge, 2004). Furthermore, a number of industrial processes such as iron and steel and cement probably lend themselves to low-cost capture (Lloyd, 2004).

Costs for CCS from electricity generation

For post-combustion systems on new 300–500 MW units of electric generating capacity, the capital cost is likely to increase by 65 to 90 percent. The cost of electricity sent out increases by 60 to 85 percent, and the cost of CO_2 emissions avoided is \$40 to \$55 per ton (\$/t). Retrofitting increases these further by about 10 percent; that is, the cost of CO_2 emissions avoided is about \$45 to \$60/t. These costs are similar for both coal-fired and natural-gas-fired stations, although the natural-gas-fired stations report somewhat lower costs, particularly in the combined-cycle mode (Lloyd, 2004).

In the case of new IGCC power stations, CO_2 recovery adds about 20 to 60 percent to the sent-out power cost and gives a CO_2 emissions-avoided cost of between \$15 and \$40/t. Retrofitting an existing power station with an IGCC is about 20 percent cheaper than retrofitting the same station with post-combustion capture.

It is unlikely that the lowest cost option, pre-combustion, can be available for at least 10 to 15 years, as most new generating capacity will probably be conventional powdered fuel combustion, for which, even on new stations, a cost penalty of at least \$40/t CO_2 avoided is likely.

For post-combustion carbon capture on operating plants, current generation produces about 190 $MtCO_2$ annually in producing about 190 TWh (Lloyd & Trikam, 2004). Present electricity prices are about R150,000/GWh. The cost penalty for capturing one ton CO_2 would

Table 4. Cost of CO_2 Capture in the United States

Capture technology	Technology status	Electricity cost USc/kWh	Electricity cost US$/ton⁺$CO_2$	Capture cost US$/ton CO_2	Total cost US$/ton CO_2	Increase in electricity cost (%)
Post-combustion	Current	3.1	30.3	26.4	56.8	87
Pre-combustion	Demo plants	4.2	41.2	21.5	62.7	52
In-combustion	Pilot plants*	3.5	34.3	11.7	46.0	34

* Estimated cost.
⁺ Electricity cost based on CO_2 emitted.

Source: Engelbrecht (2004) (Citing Canmet Energy Technology Centre.)

be about $40, or R265—a 175 percent increase in present prices. Thus post-combustion capture of CO_2 from the generation industry does not seem likely for many years (Lloyd, 2004).

Transport costs

Transport of CO_2 is the second major step in the process, as shown in Figure 1. After initial capture of the gas, the CO_2 needs to be transported to a suitable storage site for injection.

The technology to transport CO_2 is well-developed and fully proven. Typically it involves drying the gas and ensuring it meets the required composition (typically >95 percent CO_2 and <5ppm water); compressing the gas to above 6 Mpa (a pressure similar to that used to transport natural gas); and passing it down a pipeline (Lloyd, 2004).

Costs of transport of the CO_2 from the point of capture to the point of storage are difficult to estimate, as they are determined by the tonnage being transported and the distance between source and sink. Assuming a distance of about 250km between source and sink in South Africa, from Figure 4, this would suggest a transport cost of around $1.50/t CO_2 transported (Lloyd, 2004).

Storage costs

Storage costs are difficult to determine in the absence of site-specific information, but it seems reasonable to suppose that, given the rather impermeable nature of much of South Africa's sedimentary rocks, the costs would be at the upper end of those found elsewhere, that is, about $10/t CO_2.

Overall costs of CCS

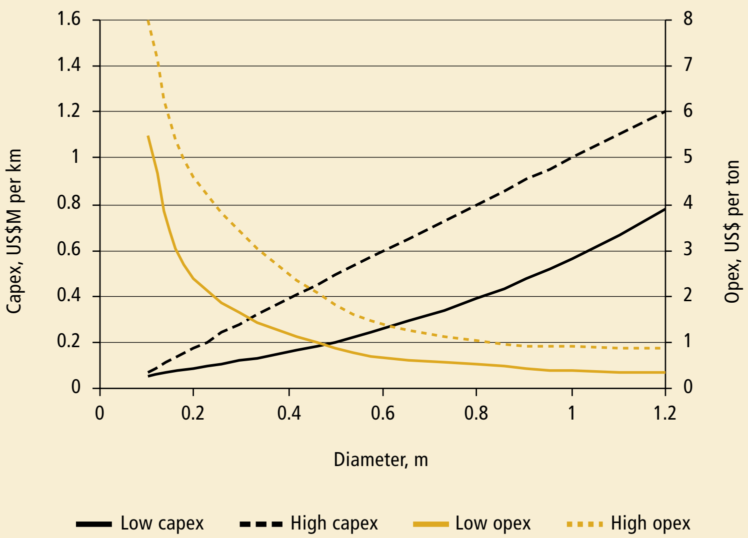
The *patterns* of likely costs of CCS in South Africa are broadly apparent. Even without knowing exact costs, it is apparent that the Sasol plant would be the most cost-effective, since it avoids the largest portion of costs, namely capture. Important gaps remain in understanding the costs of monitoring CO_2 to ensure it remains stored in geological formations or under the ocean.

The costs of capture, transport, and storage have to be added together to provide the overall costs of CCS, even before monitoring costs are quantified. Given the range of costs for different aspects, there is no single cost for CCS as a mitigation option.

As shown in Table 4, capture costs are the largest component of total costs. Pre-combustion options in the iron and steel and cement sectors may provide further options, at total costs around $20/t CO_2. Costs of carbon capture in electricity generation, the largest source of CO_2 in South Africa, are still much higher than current market prices of carbon (around $5 to $10/t CO_2). New plants would add $50 to $65/t CO_2 (capture plus storage costs), which is high. This would more than double electricity prices, and therefore does not seem likely for quite some time.

In sum, therefore, it seems entirely possible that as much as 20 percent of South Africa's capturable CO_2 emissions, or 12 percent of its total emissions, could be captured, transported and stored for about $70/t, based on maximum cost estimates. These are important figures, because a 12 percent reduction in emissions is large in comparison with the reductions accepted by the countries in Annex I to the Kyoto Protocol, and because $70/t CO_2 is between fourteen and seven times the price offered for CDM and JI credits at present. The carbon emissions credits being traded at present are the low-hanging fruit, where simple benefits are being bought cheaply, but it is still unlikely that in the long run the price of carbon will rise closer to the level at which significant quantities can be captured and stored. However, the coal-to-liquid, iron & steel, and cement industries offer a better chance for carbon credits, since in this area capture costs are signifi-

Figure 4. **Ranges of Capital and Operating Costs for High-pressure CO_2 Pipelines (based on distance of 250 km)**



Source: Engelbrecht et al. (2004)

Table 5. **Summary of Cost Estimates for Carbon Capture and Storage**

	Cost estimates	Considerations
Capture		
Coal-to-liquid plants	Very low	Very pure CO_2 stream, only compression costs
Iron & steel, cement	< $10/t CO_2	
Electricity – new plant	$40-55/t CO_2	Similar for pulverised coal and simple gas; less for natural gas combined cycle
Retro-fit	$45-60/t CO_2	Adds about 10%
IGCC	$15-40/t CO_2	Not likely in SA for the next couple of decades
Transport	$1.50 per 250 km	Cost rises with distance of storage site from sources; best storage options may be outside of SA or in ocean
Storage	$10/t CO_2	
Monitoring		Not quantified yet

cantly lower, at a maximum of $10/t CO_2 (Table 5). This implies a total of $20/t for capturing, transportation, and storage. This is low compared to the $70/t given above, but still out of range of the current carbon price of $5 to $10/t CO_2.

4.2 Social

The social benefits of CCS in South Africa can be viewed in terms of the government priorities in the area of social development and standard of living. Generically, CCS is an option in addressing climate change issues, an initiative with global dimensions. The social benefits that will accrue to South Africa as a result of following this sequestration option are principally the same as those that would result in any other initiative to reduce CO_2 in the atmosphere. At ground level, however, CCS has the disadvantage that it does not have direct social benefits to communities, which may be the case in other climate change mitigation or sequestration projects that would have some or all the ingredients of CDM projects.

For South Africa, where government policy has sought to keep increases in retail electricity prices below inflation, increased prices due to CCS would add significant pressure on social delivery. In the next few years, as new power stations will be needed, the price of electricity is expected to rise anyway. Adding CCS would add to the cost burden. If implemented, special measures to protect poor households from such increases would be needed. Currently, the government has a policy on providing free electricity to the poor, an initiative called "poverty tariff" in which a range of 20 to 50 Kwh per month of free electricity is provided to poor households.

Co-benefits for local sustainable development

The aspirational goals of the RDP (see section 1.1) serve to illustrate the importance of socioeconomic development, conceived around delivery of basic services, in the broader context of South African policy. While the status of RDP has become uncertain and lives in tension with macroeconomic policy, these overall development objectives continue to provide an important context for energy policy as well.

CCS poses a conflict in terms of energy policy. On the one hand, it offers a potential to reduce the environmental impacts of coal, particularly in the synfuel industry. On the other hand, at current costs (see section 4.1), implementing CCS would raise prices of electricity and liquid fuels. *Affordable* access to modern energy services is an important energy policy objective (DME, 2004, 1998). The success in raising rates of electrification of households from about one-third in the early 1990s to 67.9 percent by 2002 (NER, 2002) was made possible in part by cheap coal-fired generating capacity. Given that alternative supply options are not yet cost-competitive with coal-fired power, there is a tension between the goals of universal access to electricity and moving toward a cleaner fuel mix.

As shown in Table 3, the key area where CCS, in accordance with sustainable development criteria for South Africa, plays a significant role is in the area of technology transfer. Direct social benefits to communities are quite low. As a mitigation option focused exclusively on climate change, CCS would need to be motivated only on the basis of the global benefits accrued from the reduction of CO_2 in the atmosphere. Impacts on environmental quality, equity, and poverty alleviation are mixed, some positive and negative.

The key negative impact appears likely to be socio-economic. At current prices in the carbon market, the revenues from selling carbon credits would not be sufficient to offset the costs of CCS. If a CCS program were to be reviewed under the dual advantages typical of CDM projects, then it would be quite unlikely to get government approval, since it offers little in terms of direct local or even regional benefits. In fact, CCS is likely to be seen as a disadvantage to communities since, as shown above, they can result in increased costs of energy services. Presumably, the cost of CCS will eventually be relayed to the energy service customers. It is possible, however, that customers could be cushioned from such added operation costs if CCS projects were to be eligible for CDM. This might require making some allowances in the sustainable development criteria for CCS CDM projects to be approved.

CCS might play a role in slowing the transition of South Africa's energy economy to a more diverse fuel mix. Coal accounts for about three-quarters of total primary energy supply in South Africa (DME, 2002), and 93 percent of electricity generation (NER, 2002). In the context of the climate change debate, a key energy development objective has to be borne in mind—increasing access to affordable energy services. This policy goal has assumed the status of a "non-negotiable" issue in South Africa energy policy. However, if extending access to electricity continues to rely on coal-fired generation capacity, the environmental implications are considerable. Concerns about job losses in both the electricity and coal mining sectors are additional arguments in favor of a gradual transition to a lower-carbon energy economy, although these should be weighed against the employment potential of other options (AGAMA, 2003). CCS might mitigate the GHG effects on continued use of coal, and hence dilute motivation for diversion to other energy sources in addition to coal.

This argument raises a number of other issues concerning the implications of a global CCS. Would it mean a continuation or a business-as-usual scenario for CO_2-emitting technologies simply because there is a huge potential for capturing and storing the emitted CO_2? Would it be at the cost of other carbon-saving technologies like renewable energy? South Africa's sustainable development criteria put significant weight on social issues like job availability. A CCS initiative that maintains the status quo of the coal industry in terms of exports and job availability might find considerable favor among decision makers in South Africa.

Institutional capacity

A solid institutional framework in South Africa would be necessary for effective implementation of CCS mitigation options. The environmental implications of CCS and infrastructure requirements will necessitate key players becoming involved. For example, organizations dealing with environmental monitoring and regulation of pipelines may need to be strengthened.

Where pipeline transportation infrastructure is in place, then issues of access by different players to the pipeline network would have to be considered, just as in natural gas pipeline transportation. The same issues would be relevant to CO_2 storage area access. A decision would have to be made to either use existing regulatory organs, such as the Gas Regulator, and redefine its mandate. Further functions would need to be integrated into a National Energy Regulatory Authority, which is expected to combine electricity, gas, and petroleum regulators in South Africa within five years.

South Africa would probably have the institutional capacity to implement a CCS project. However, CCS would still present new areas in which capacity development would be required. An important concern is whether

there would be sufficient capacity to monitor and/or independently verify the long-term storage of CCS. These institutional issues are likely to have implications for the overall cost of implementing CCS initiatives in SA.

It will also be necessary to enact legislation that will not only explicitly consider transportation and storage of CO_2, but also consider liability and environmental requirements. The Department of Environmental Affairs and Tourism (DEAT) and the Department of Minerals and Energy (DME) would naturally be important players.

4.3 Environmental and safety concerns

Safety issues

Carbon dioxide occurs naturally in the air; at atmospheric concentrations, it is nontoxic. Being a nonflammable gas, the most probable concern for humans, plants and animals would be exposure to high concentrations of carbon dioxide. With CCS, risks from CO_2 would occur where there is the possibility of high concentrations due to leakage, either acute or long-term, or due to the forms in which it would be transported or stored. In the atmosphere, the concentration of CO_2 is around 0.3 percent. At high concentration, above 10 percent, CO_2 is quite lethal, causing death due to asphyxiation. It is 1.5 times as dense as air, and if atmospheric oxygen is displaced such that oxygen concentration is 15 to 16 percent, signs of asphyxia will be noted. If CO_2 leaks into surface soils, displacement of oxygen can be lethal for plant life.

In most cases, CO_2 would be handled under high pressure, whether in transportation or storage. The safety risks here would mainly be those associated with process, structural engineering, or transport infrastructure failure. Some intermediate storage of CO_2 will be needed to cope with variability in supply, transport, and storage, particularly if CO_2 is transported by rail, road, or ship. The highest exposure is likely to result from failure of transport pipelines, causing a large release of CO_2 in gaseous form. It is possible that such releases could endanger human life and other biodiversity. The risk of problems from pipe leakage is very small; to minimize risks, CO_2 pipelines could be routed away from large population centers. Generally speaking, handling of CO_2 should be relatively safe, especially when we consider that other potentially hazardous gases such as natural gas, ethylene, and LPG are already being transported and stored with relatively few problems.

An extreme example of the hazards of CO_2 is that of Lake Nyos, a volcanic crater lake in Cameroon, which emitted large quantities (estimated at 80 million cubic meters) of CO_2, causing 1,700 deaths and loss of livestock up to 25km from the crater (Johnston and Santillo, 2002).

This natural phenomenon, while illustrative of the dangers of high concentrations of CO_2 in low-lying areas, is unlikely to be reflective of the risks posed by CCS.

While aboveground equipment for handling CO_2 would be subject to the same processes and standards for handling gaseous products under high pressure, monitoring of CO_2 levels would still be important. This can be done by placing sensors at selected locations that would measure the amount of CO_2 in the atmosphere. The monitoring systems should be able to sound an alarm siren if CO_2 gas concentrations in the air around large volume storage points reach dangerous levels. For people living near CCS infrastructure, it would be critically important to provide awareness-raising programs regarding possible hazards and how to respond to hazardous situations.

Geological storage concerns

With geological reservoirs, the assumption is generally made that such formations have held hydrocarbons or liquids for considerable durations of time, and thus injection of CO_2 into the reservoirs and properly sealing them is likely to maintain the original conditions. However, the pressure at which CO_2 would be stored in the reservoirs would be an important factor to consider, albeit in maintaining similar conditions as the case might have been before depletion of gas or oil. Injection of natural gas into depleted oil or gas fields is a common practice in the petroleum industry, and a number of oil and gas reservoirs have been successfully used to store natural gas. CO_2 storage would therefore present a similar practice, and experience on natural gas storage can provide a useful example for development of CO_2 storage in oil and gas reservoirs.

With abandoned gold or coal mines, however, more attention would be needed, since mining processes in this case usually involved use of explosive and other equipment that causes considerable vibrations. Mines in South Africa have created areas of seismic activity associated with mining processes. There is thus a strong likelihood that subsidence will have induced fractures in the rocks, which would create a poor sealing of the rock and a possible route for CO_2 to escape to the atmosphere by slow leakage or abrupt eruption.

Research, development, and demonstration projects examining environmental concerns of CO_2 storage are under way in Canada, Europe, and Japan. There are still a lot of uncertainties and informational gaps related to ocean and geological storage of CO_2. The environmental concerns of CCS would thus need to include an understanding of both exposure and effects of carbon dioxide in various situations associated with carbon dioxide transportation, injection into storage points, or leakage from storage points.

5. CONCLUSION

It is clear that South Africa has a potential for CCS. The major potential for capture lies in the major point sources of CO_2 emissions—electricity generation, synfuels, oil refineries, and energy-intensive industries such as iron and steel, nonferrous metals, pulp and paper, and cement. The highest quantified storage potential is in geological formations. There is limited storage potential in abandoned mines, ocean storage, and in oil and gas fields. Major issues of concern include porosity and permeability of the geological formations, as well as environmental, safety, and legal issues.

In pursuing the CCS initiative in South Africa, major obstacles include the high cost of capture and storage, which would increase the cost of energy services. The benefits from international carbon trade are highly unlikely to offset the costs of CCS, even in the long run. In terms of South Africa's sustainable development criteria, CCS could have a number of positive elements, the most outstanding being technology transfer. Social benefits appear to be quite low.

CCS, in the context of South Africa's climate change strategy, could be part of an agenda to facilitate the transition from a coal-dependent energy system to a more diversified one, making the coal "cleaner," but there is a need to conduct further studies on how CCS compares to other mitigation and sequestration options in terms of costs and long-term sustainable development benefits.

ENDNOTES

[1] SA ratified the UNFCCC in August 1997 and the Kyoto Protocol in 2003.

[2] The Department of Minerals & Energy and Eskom participate in the CSLF's policy group. The participants in the technical group are from Sasol and AngloCoal (Surridge, 2004). Together with other researchers, Eskom and Sasol are also involved in the preparation of the IPCC special report on CCS.

[3] Sasol is, however, switching feedstock from coal to gas over a period of time; a gas pipeline from Mozambique started to deliver gas in February 2004.

[4] React the fuel with oxygen or steam, create syngas (CO and H_2); shift reaction to CO_2 and H_2; CO_2 separated by chemical absorption.

[5] The range depends inter alia on load factors, excess air supply and similar factors; some measurements have been conducted by Lloyd & Trikam (2004).

[6] CO_2 emissions dominate South Africa's total GHG emissions. Electricity CO_2 emissions constituted 37 percent of total GHG emissions in the 1994 inventory. However, since this report considers capture of CO_2 rather than other GHGs, the comparison to total CO_2 is the relevant one.

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