CLIMATE CHANGE AND CARBON DIOXIDE (CO_2) SEQUESTRATION:

AN AFRICAN PERSPECTIVE*

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Since 1990 carbon dioxide emissions in Africa have increased by about 50%. The total carbon dioxide emissions of the entire African continent are not, however, anywhere near those of countries such as India or China. Yet certain African countries have per capita emissions comparable to some European countries. What is the outlook for Africa? How should African countries respond as it becomes increasingly likely that climate change is occurring? Increased industrial growth and more foreign investment in Africa, especially in countries that are politically and economically stable, have led to huge commercial developments such as the In Salah gas project in Algeria, which releases more than a million tons of carbon dioxide annually; and synthetic fuel plants and power stations in South Africa that generate more than 350 million tons per year. In this perspective should some African countries be required to limit greenhouse gas emissions or should they be immune to 'environmental taxation'? This paper critically reviews the carbon dioxide problem in some parts of Africa and its role in climate change.

1. Carbon Dioxide: A Global Threat?

Climate change is at the centre of increasing global concern. Average air and sea temperatures have increased appreciably during the last century. The international and scientific communities are in agreement that most of this increase is due to the rising carbon dioxide (CO_2) concentration in the Earth's atmosphere mainly from the burning of coal, oil and natural gas. Amongst possible solutions for the reduction of excessive greenhouse gases in the atmosphere is the capture and sequestration of carbon dioxide[1]. This paper focuses on the extent to which some countries in Africa have contributed to global warming, and explores some of the solutions proposed to sequester carbon dioxide to alleviate the impact of climate change.

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The recently released Fourth IPCC Assessment Report[2] declares:

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level.

This is a definitive statement from the Intergovernmental Panel on Climate Change (IPCC) that global warming is happening. The IPCC also maintain that it is very likely[2] that much of the observed warming since the middle of the 20th century can be directly attributed to increasing concentrations in the atmosphere of anthropogenic greenhouse gases – gases resulting principally from human activities. Extensive studies of ice cores reveal that atmospheric concentrations of three of the principal anthropogenic greenhouse gases – carbon dioxide, methane and nitrous oxide – have been increasing steadily since the beginning of the industrial era[2,3]. Carbon dioxide is the major contributor (between 50 and 60%) to the anthropogenic greenhouse effect, while methane and nitrous oxide, as well as the halocarbons and tropospheric ozone, together contribute the remaining 40–50%[3,4]. Because of this, considerable time and effort are being spent in trying to control emissions of anthropogenic carbon dioxide.

If we consider the source of this anthropogenic carbon dioxide, the majority is due to the use of natural gas, oil and coal to produce energy or, for transportation. For example, global emissions of carbon dioxide resulting from the combustion of fossil fuels[5] in 2003 represented 26.0 Gt (table 1)[6]. The rest of the emissions, estimated to be ~6 Gt per year[3], arise through changes in land use, principally as a result of deforestation to create agricultural land. Although the contribution of anthropogenic carbon dioxide may seem to be insignificant when compared to the ~200 Gt of carbon (> 700 Gt of carbon dioxide) that naturally exchanges each year between the atmosphere, the oceans and the land masses[3,4], it is sufficient to influence the radiation balance of the Earth.

2. Outlook for Africa

When the conclusions of the IPCC[2] are considered within an African perspective, the questions that come to mind are: to what extent is the African continent contributing to the problem of global warming through its emissions of carbon dioxide? And, should some countries in Africa be required to limit their emissions under the Kyoto protocol? It is clear from table 1 that Africa is responsible for only a small part (3.6%) of global carbon dioxide emissions arising from fossil fuel use, despite having a population of close to 900 million – roughly 14% of the world's population[7]. With 0.94 Gt of carbon dioxide, the African continent emits less than single nations such as China, India, Russia, Japan and the USA[8]. In addition, per capita emissions in Africa (1.1 t/year of carbon dioxide), represent 25% of the world average, and a mere 5% of annual per capita emissions in North America (table 1). However, when the data for Africa are further refined, a very different picture emerges. Figure 1 shows that considerable variation in total emissions of carbon dioxide exists in the different regions of Africa, with Northern Africa and Southern Africa being responsible for a significant proportion of the emissions on the African continent[8]. A closer look tells us that South Africa produces 40% of the emissions of the continent, or 356 million tons of carbon dioxide annually, while Egypt, Algeria, Nigeria, Libya and Morocco together provide a further 44%. There is also a significant imbalance when per capita emissions of carbon dioxide for

TABLE 1: CARBON DIOXIDE EMISSIONS FOR THE YEAR 2003 [6].

	Carbon dioxide emissions (Gt of CO_2)[a]	Per capita carbon dioxide emissions (t of CO_2)[a]
World	26.0	4.1
Africa	0.94	1.1
Asia and Pacific	9.72	2.6
Europe	6.80	8.3
Latin America and Caribbean	1.33	2.4
North America	6.43	19.8
Polar	0.001	10.0
West Asia	0.79	7.2

[a] Gt = gigatons; t = tons; 1 Gt = 109 tons.

individual African countries are reviewed[8]. We find that emissions in Libya (9.20 t/year), South Africa (8.18 t/year) and Algeria (5.13 t/year) are all greater than the global average (table 1). Yet, in contrast, approximately half of African countries have annual per capita emissions less than 0.4 t of carbon dioxide (or 10% of the global average).

A similar situation exists when fossil fuel use is considered[9]. The breakdown of fossil fuel use in Africa for the year 2005 appears in table 2. We see that three countries – South Africa, Egypt and Algeria – are responsible for about 70% of total fossil fuel consumption, with South Africa alone accounting for 40%. In other words, the remaining >50 countries use only 30% of the total fossil fuel consumed on the African continent. Clearly, African countries represent a wide spectrum when both fossil fuel use and emissions of carbon dioxide are considered, and also when responsibility for global warming is assigned. And yet, although all African countries have ratified the United Nations Framework Convention on Climate Change (UNFCCC), none is an 'Annex 1' country. They are all considered to be developing countries and, as a result, are not required to control or reduce their emissions of greenhouse gases under the Kyoto Protocol. Bearing in mind the low overall emissions for the African continent, this appears to be a reasonable situation. Nevertheless, when the high per capita emissions in South Africa, Libya and Algeria are considered, some form of action to limit emissions in these countries seems justifiable.

In the coming few decades, can we expect carbon dioxide emissions in Africa to grow to a level that will warrant individual countries introducing measures to limit their emissions? If so, what major factors would contribute to this escalation? Figure 1 reveals that carbon dioxide emissions in Africa have actually increased by almost 50% since 1990, with most of the rise attributable to the trends in Northern and Southern Africa. Two factors suggest that total emissions will continue to rise in the coming decades. First, in the period 2000–2005 Africa experienced a relatively high rate of population growth of 2.2%, compared to a global average of 1.2%[7]. Fertility rates (~ 5 children per woman) are currently among the highest in the world. Although these rates are declining, we can still expect that the African population will increase significantly in the coming decades. Second, the African continent is relatively well endowed with reserves of fossil fuels (table 3)[9]. At present, Africa supplies 12% of the world's oil and 6% of its natural gas. But, only about 25% of the oil and 45% of the natural gas produced in Africa are consumed domestically. As the economies of the African countries grow, partly through revenues from oil and natural gas, and as standards of living increase, we can expect greater domestic consumption of fossil fuels; and therefore, enhanced emissions of carbon dioxide. Further, with proven oil and natural gas reserves of 9.5% and 8.0%, respectively of global reserves, Africa is set to remain a significant provider of fossil fuels for the coming years.

Based on these observations, what kind of response seems appropriate for the African continent?

FIGURE 1: TOTAL CARBON DIOXIDE EMISSIONS FOR THE AFRICAN REGIONS [6].

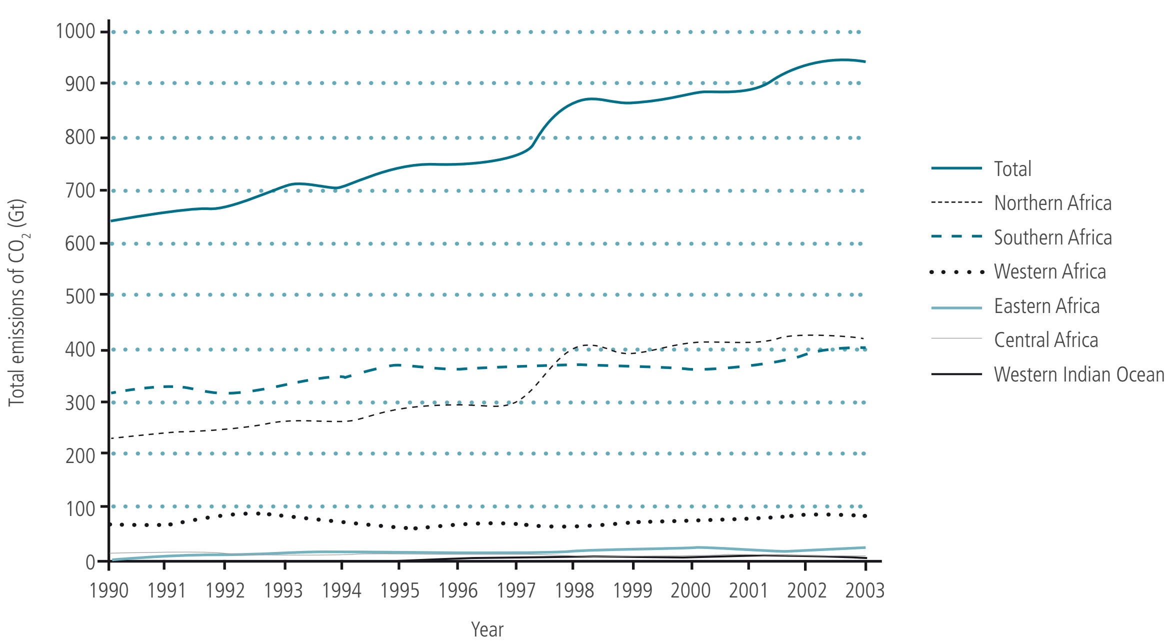


TABLE 2: FOSSIL FUEL CONSUMPTION FOR THE YEAR 2005 (MILLION TONS OIL EQUIVALENT)[9].

	Oil	Natural gas	Coal	Total
Algeria	11.2	21.7	0.9	33.8
Egypt	29.2	23.0	0.5	52.7
South Africa	24.9	–	91.9	116.8
Rest of Africa	64.0	19.4	7.0	90.4
Total Africa	129.3	64.1	100.3	293.7
% of world consumption	3.37%	2.59%	3.42%	3.18%

3. Carbon Management in Africa

It is difficult to prescribe a management plan for Africa because of the widely different stages of development of the countries and because the future of the continent depends largely on its stability. War-torn areas, civil unrest, poverty, disease and famine tend to make its future appear bleak. On the other hand, one can imagine a more optimistic future that will result in greater economic development; and, in the wake of this growth, Africa could indeed seek to develop its own program of carbon management.

One possible scheme that would allow the wide diversity of situations across the African continent to be confronted with respect both to fossil fuel use and deforestation could be similar to that proposed by Socolow, Pacala and co-workers [10,11]. This scheme is designed to consider a range of initiatives to stabilize emissions in the coming 50 years to permit a transition to a (relatively) fossil fuel-free future. They describe a plan (below) for which current technologies exist and propose that, by introducing these measures today and subsequently scaling up activities over the next few decades, carbon dioxide emissions can be capped at current levels (about 26 Gt of carbon dioxide). This would still result in a further increase in atmospheric carbon dioxide concentrations above the current level of 379 ppm, but could be expected to limit concentrations to the range of 500 ± 50 ppm, which is considered to be an acceptable target in order to avoid a significant level of climate change[10]. The following options have been proposed:

- improvements in energy efficiency in areas such as electricity generation and use, and in the transport sector;
- an increased use of renewable energy, including wind and solar (photovoltaic and passive);
- a change in land use to increase natural sinks, such as by reducing deforestation and starting afforestation; and
- the introduction of carbon management measures, such as decarbonization (switching from coal and oil to the lower carbon-content natural gas), and the capture and storage of carbon dioxide (so-called carbon sequestration).

Clearly, under this scheme, the majority of countries in Africa that are currently emitting little fossil-fuel carbon dioxide (both on a per capita and total basis) would focus on avoiding becoming dependent on fossil fuels by appropriate use of renewable energy and better land use management. This would be achievable through use of the Clean Development Mechanism, within the Kyoto Protocol. It is important to remember that, although these countries produce little carbon dioxide from fossil fuel use, they do contribute to global warming through their extensive use of biomass, and in particular wood-derived products, for their energy. Although biomass use is normally considered to be carbon-neutral this only applies if the forest products are renewed. Sadly, this has not been the case in these countries and as a result Africa has traditionally had one of the highest rates of deforestation in the world (~ 0.8% per year during the period 1990–2000[12]).

Turning our focus now to the remaining countries – such as South Africa, Algeria and Libya – who are either major emitters of carbon dioxide or have high per capita emissions, we find that both Algeria and Libya are important producers of oil and natural gas, while South Africa is an important producer (and consumer) of coal. It is clear that these countries need to face the question of their current carbon dioxide emissions. In addition to improved energy efficiency and increased use of renewables, they have the additional possibility to introduce other measures such as decarbonization, in the case of South Africa, or carbon dioxide capture and sequestration[1].

Although there are very few activities in these countries directed to the introduction of carbon dioxide capture and storage, a clear potential should be recognized whenever there are large stationary sources of carbon dioxide emissions, such as where there are thermal power stations, heavy industrial sites or where oil and natural gas production is occurring.

TABLE 3: FOSSIL FUEL PRODUCTION AND RESERVES (2005 DATA) [9].

	Oil		Natural gas		Coal	
	Share of global production	Share of global reserves	Share of global production	Share of global reserves	Share of global production	Share of global reserves
Algeria	2.2%	1.0%	3.2%	2.5%		
Angola	1.6%	0.8%				
Cameroon	0.1%	< 0.1%				
Chad	0.2%	0.1%				
Rep. of Congo (Brazzaville)	0.3%	0.1%				
Egypt	0.9%	0.3%	1.3%	1.1%		
Equatorial Guinea	0.5%	0.1%				
Gabon	0.3%	0.2%				
Libya	2.1%	3.3%	0.4%	0.8%		
Nigeria	3.2%	3.0%	0.8%	2.9%		
South Africa					4.2%	5.4%
Sudan	0.5%	0.5%				
Tunisia	0.1%	0.1%				
Zimbabwe					0.1%	0.1%
Rest of Africa	0.1%	< 0.1%	0.3%	0.7%	< 0.1%	0.1%
Total	12.0%	9.5%	5.9%	8.0%	4.3%	5.6%

4. Saharan Monument: In Salah CO_2 Storage Project

Storing carbon dioxide underground has shown considerable promise[12]. Interring 'global warming', as it is called, has to some extent mitigated the environmental impact of fossil fuel production. As a result, geological sequestration has opened up a vista of opportunities for reducing carbon dioxide emissions to a level that is becoming globally acceptable. There are several reasons for this. Sub-surface storage has diverse and practical geomorphological structures for engulfing millions of tons of carbon dioxide underground. Essentially there are three types of storage facilities underground that are currently implemented for such sequestration purposes: oil and gas reservoirs, intractable coal seams and deep saline aquifers. Each one comes with its own merits and drawbacks. For example, oil and gas reservoirs possess rock formations that can absorb the carbon dioxide, but at the same time dissolution of the rock is possible. In the case of uneconomical coal beds, the gas is adsorbed on to the surface of the seams, but gradual leakage could occur when the adsorbed gas is displaced. The Saharan environment is ideal for long-term sequestration of carbon dioxide because it has sub-surface geological structures that are geochemically stable and highly suitable for this purpose. An outstanding example is the recently developed In Salah project in Algeria (figure 2), which is a unique development in Africa, and an economic boost for the country[13,14]. In Salah bears the name of the nearest settlement to the gas fields, approximately 150 km from the Krechba gas plant. The field uses deep saline aquifers to bury the captured carbon dioxide (figure 3) and is of considerable international interest as it serves as a practical model of industrial-scale carbon dioxide storage for several potential storage sites in the North Sea and North America.

The In Salah gas field is a $3.5 billion project inaugurated by BP 1200 km south of the capital Algiers (figure 2), and is a token of increasing foreign investment in Africa. This includes installation of a 520 km pipeline northwards from Krechba, deep in the Sahara desert, to Hassi R'Mel, which is connected to a natural gas liquefaction plant on the Algerian coast and linked to export pipelines to Europe. The main objective of the project is to market gas from the remote In Salah region and simultaneously develop the Saharan environment. This area is arguably one of the most stringent environments in the world. This mammoth project is a joint venture between BP and its partners Sonatrach and Statoil, and a vital element includes capture of the carbon dioxide produced and its reinjection into the gas reservoir[15,16]. One of the great benefits of sequestering carbon dioxide underground is that it can play a major role in enhanced oil recovery (EOR) and enhanced gas recovery (EGR). The mechanism of such recovery processes is well known and the operation at Krechba clearly has the potential for this[16]. Therefore, future planning of the operation is crucial to take into account all possible factors that could restrict carbon gas emissions.

FIGURE 2: ALGERIA MAP AND IN SALAH FIELD [23].

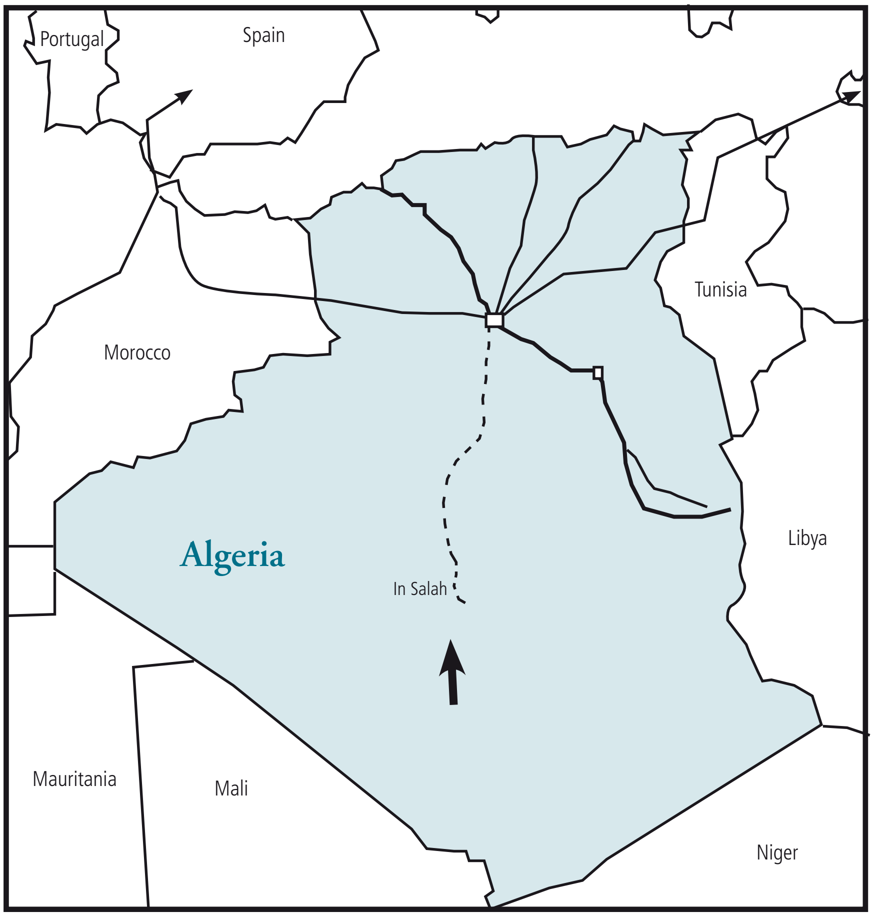
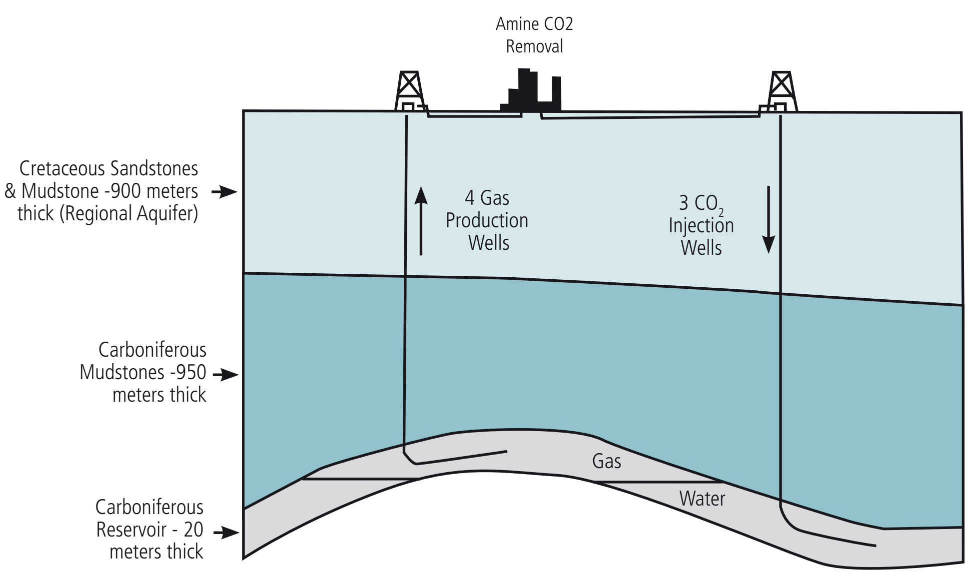


FIGURE 3: IN SALAH GAS AND INJECTION WELLS [23].



The re-injection process is estimated to reduce atmospheric emission of over one million tons of carbon dioxide annually, but this figure is expected to grow with escalating development. In view of this, restrictions on carbon dioxide production should be implemented to keep abreast of regulations governing climate change and sustainable living. No doubt, confident and safe planning of the operation will contribute to ecofriendly conditions and sustainable development. Clearly, the success of the project is linked to controlling carbon dioxide emissions in Algeria. As a gesture in this direction the oil companies themselves could take the initiative to propose measures consistent with the Kyoto Protocol.

5. South Africa: CO_2 Giant

The new South Africa is barely 13 years old and is in the process of attaining political and social equilibrium. It produces roughly 400 million tons of carbon dioxide per annum – the highest in Africa. Yet it is not required to limit its carbon dioxide emissions under the Kyoto Protocol. Nevertheless, pressing environmental and conservation matters are keenly pursued, and restrictions on carbon dioxide emissions will soon be at the forefront of these issues. The country has definitely taken strides in earmarking sites for carbon dioxide sequestration but its progress in this respect has not been widely reported. Therefore, it is worthwhile reviewing some of its future plans and salient options for geological storage[17].

Much of the emissions in South Africa arise from power stations (40%) and synthetic fuel plants, like Sasol (Suid Afrikaanse Steenkool en Olie/ South African Coal and Oil). Minor contributions to the annual carbon dioxide emissions originate from industrial processes (7%), transport (9%) and agriculture (11%). Sequestration plans are at the embryonic stage, where various options for storing the carbon dioxide are being explored. The potential for geologic storage is wide. South Africa is well known for its gold mines, and one storage possibility is abandoned gold mines, a few thousand meters underground. The likelihood of faults in the structures of these mines could, however, result in leakage to the atmosphere – with disruptive effect. Another drawback is the proximity of these abandoned mines to working ones. But, depleted gold mines have the capacity to store roughly 10 million tons of carbon dioxide, and if closely monitored, could be controlled to restrict environmental catastrophes. Coal is another resource that is plentiful in South Africa and with it comes the feasibility of burying carbon dioxide in unused coal mines[18]. This is particularly attractive as it could result in enhancing coal bed methane (ECBM) production. A distinct advantage is that these abandoned coal seams are usually found close to the sites of electricity production plants, and so transport of the emitted carbon dioxide would not be costly. Although the storage capacities of these beds are about 1% of the total annual carbon dioxide emissions, the methane gas obtained in this way could be used for power generation, and plans are underway to commence production in the Waterberg coalfield in the north (figure 4).

Figure 4. Potential sites (shaded areas) for carbon dioxide sequestration in South Africa[17]. Apart from abandoned gold and coal mines, sedimentary basins encompassing saline aquifers have considerable potential, especially the ones located in the Kalahari Karoo and Great Karoo, in the north-west and south-east, respectively (see map in figure 4). The advantages of saline aquifers have been discussed above; but of importance is that these storage areas should be close enough to the source point of the emitted carbon dioxide to prevent exorbitant transport costs. Most of these basins are remote from major point sources, but the Great Karoo basin covers considerable ground and would be the one to exploit for the purpose of geologic sequestration. It possesses the required depth, thickness and extent, and is composed of satisfactory geological structures to be considered for long-term sequestration. A point to consider is that in South Africa conservation of wildlife is a priority and the impact of a sequestration scheme close to wildlife conservation areas would be unfavourable. Hence storage at the Lembombo Karoo site (see map in figure 4), for example, would lead to considerable opposition as it borders the famous Kruger National Park[17]. The use of abandoned coal mines close to residential areas could also be a drawback.

In addition to the storage possibilities discussed above, other options have been reviewed. Deep ocean sequestration and chemical capture of carbon dioxide are alternatives that have been considered[18], but these options need to be extensively explored before they can be implemented. For example, the option of sequestering carbon dioxide under water is not favourable. Explosions in the Cameroon under Lake Monoun and Lake Nyos in 1984 and 1986, respectively, led to the emission of huge masses of carbon dioxide that engulfed these areas causing the death of hundreds of people by asphyxiation[19]. Successful degassing projects were initiated at Lakes Nyos and Monoun to avert similar disasters in the area in uture. The possibility of such a tragedy repeating itself has deterred some countries from considering underwater burial of carbon dioxide.

Clearly, secure and safe storage of the carbon dioxide is an essential requirement[20]. For such technology, safety has been achieved by risk management programmes that make use of information from site characterizations, operational monitoring and scientific and engineering experience. It is most important to monitor subsurface storage, so that leakage at any stage of the operation may be immediately detected. A wide range of monitoring tools is generally implemented such as: seismic profiling, electromagnetic surveys, and CO_2 sensors. Environmental health and safety are of the utmost concern, and the future of carbon dioxide sequestration, in South Africa and elsewhere, depends on efficient and reliable monitoring and risk assessment programmes.

South Africa dominates the emissions of Southern Africa. South Africa's neighbours produce only a fraction of its total carbon dioxide emissions. For example, Zimbabwe, Botswana and Namibia roughly produce: 3.5%, 1% and 0.6%, respectively, of South Africa's total emissions. Therefore, expediting the use of available resources for carbon dioxide sequestration in South Africa cannot be underestimated. As stated above, more than a decade has elapsed since the advent of the new South Africa, and understandably there has been a need to uplift the economy and living standards of the majority of the population. However, it cannot be ignored that South Africa is Africa's biggest carbon dioxide contributor, and immediate attention must be given to carbon dioxide reduction and containment in the race to halt climate change.

6 'Apocalyptic' Future?

In April 2007, the IPCC warned the globe of an 'apocalyptic' future if the projected impact of climate change is not alleviated[21]. Strident voices at the United Nations called for serious reductions in carbon dioxide emissions worldwide. Stringent measures and lower targets in carbon gas emissions are needed or else 'a third of the world's animal and plant species could become extinct'. The sad message also proclaims that in the wake of weather changes such as tempestuous tropical storms, changing rainfall patterns, accelerated melting of Arctic ice and glaciers, drought, flooding and water stress (brought about by enhanced global warming) the poorest countries will be the hardest hit. Africa is the poorest continent in the world and its 'Annex 1' countries should sincerely take responsibility and contribute towards reducing carbon dioxide emissions.

Recent studies have shown that, although the African continent as a whole is responsible for only a small part of the global carbon dioxide emissions, the region is especially vulnerable to the likely impacts of projected climate change[21]. It has been estimated that, by 2020, up to 250 million people in Africa could be affected by water stress due to a combination of climactic change and increasing pressures resulting from rapid population growth. For example, many countries in Africa depend heavily on rain-fed agriculture for their economies as well as for food security, and this is clearly related to the quality of the rainy season and the climate. In addition, some countries in west and central Africa are particularly likely to be affected by sea-level rise, resulting from climate change, due to the rapid growth of urban centres in coastal regions. If the worst effects of climate change should befall these countries, many of which already suffer from poverty, seasonal drought and increasing numbers of HIV patients with resulting very large numbers of orphans, the apocalyptic future will be another mass disaster for Africa. This is what is meant by an earlier IPCC report [22] which concluded:

> The African continent is particularly vulnerable to the impacts of climate change because of factors such as widespread poverty, recurrent droughts, inequitable land distribution, and overdependence on rain-fed agriculture. Although adaptation options, including traditional coping strategies, theoretically are available, in practice the human, infrastructural, and economic response capacity to effect timely response actions may well be beyond the economic means of some countries.

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