THE IMPLEMENTATION OF URBAN GREENING PROJECTS FOR ENERGY EFFICIENCY AND GREENHOUSE GAS REDUCTIONS IN POTCHEFSTROOM, SOUTH AFRICA

By

G. NEL

Submitted in fulfilment of the requirements for the degree Magister Scientiae in Geography and Environmental Science at the

North-West University

Potchefstroom

Supervisor: Dr L. A. Sandham

Assistant Supervisor: Prof J. G. Nel

ABSTRACT

Greenhouse Gas (GHG) concentrations in the atmosphere have increased by as much as 30% since pre-industrial times due to the accelerated rate of GHG emissions. This phenomenon may result in elevated average global temperatures, changes in regional precipitation rates, increased incidence and intensity of extreme weather events, and a rise in the average sea level.

Although there is a substantial amount of research that attempts to verify several of the projections on climate change that have been detailed by the IPCC report, there is still a gap in the understanding of how local authorities in South Africa can contribute to reducing greenhouse gas emissions at a local level to contribute to this global issue.

This study analyses the possibilities and challenges for the cost-effective reduction of GHG emissions associated with the use of energy, methane recovery and utilisation, and CO_2 sequestration in intermediate-sized African cities. This is achieved by explaining the efforts and achievements of the city of Potchefstroom as a case study. In the city of Potchefstroom, certain urban greening projects were carried out to meet specific service demands in the respective market sectors, while the application of technology was, compared to previous practice, also accompanied by significant reductions in the quantity of GHG emitted. A total 44.84% reduction in GHG emissions was achieved in Potchefstroom after the implementation of the GHG reduction projects. The Potchefstroom experience has shown that the deciding factor for getting the mayor, councillors and other major role players committed to sustainability and

GHG reduction issues, was the possibility of immense economic saving obtained by the GHG reduction projects.

SAMEVATTING

Die totale konsentrasie van Kweekhuisgasse (KHG) in die atmosfeer het met ongeveer 30% toegeneem sedert die voor-industriële tyd as gevolg van die toename in die tempo van KHG emissies. Daar word voorspel dat die toename in KHG vlakke in die atmosfeer onder meer kan lei tot die styging in die globale gemiddelde temperatuur, veranderinge in die regionale neerslag, toenemede voorkoms en verhoging in die intensiteit van ekstreme weerstoestande en die styging van die seevlak.

Alhoewel daar tot op hede reeds 'n substansiële hoeveelheid navorsing gedoen is rondom globale verwarming, die kweekhuiseffek en kweekhuis gasse, is daar tans steeds 'n gaping in hierdie navorsingsveld. Die rol wat plaaslike regerings in Suid Afrika kan speel om die vermindering van KHG plaaslik te verminder en so by te dra tot oplossings vir die globale problem is steeds onduidelik.

Die studie ondersoek die geleenthede en uidagings wat stede van intermediere grootte in Afrika het, om koste-effektief hul KHG emissies wat met energie verbruik gepaart gaan te verminder. Die studie kyk verder na ander opsies om KHG emissies te verminder soos CH_4 vaslegging en die gebruik daarvan as skoner energiebron, asook na CO_2 sekwistrasie. Dit studie sal die pogings en resultate wat deur die stad van Potchefstroom behaal is gebruik as voorbeeld. 'n Belangrike deel van die van die studie handel oor die identifikasie van alternatiewe bronne vir skoner energie wat koste-effektief deur stede gebruik kan

word. Deur die gebruik van die goedkoper, dog skoner energie, kan daar 'n vermindering in stede se KHG emissies teweeggebring word. Die stad van Potchefstroom het deur die implementering van die KHG stedelike vergroenings-projekte, 'n totale besparing van ongeveer 44.84% in die jaarlikste KHG emissies behaal. Die Potchefstroomse ondervinding het getoon dat die moontlikheid van omvattende finansiele besparings deur die KHG verminderingsprojekte, een van die mees belangrikste faktore is om die burgemeester, raadslede asook ander besluitnemers oor te haal tot volle betrokkenheid en oorgawe.

ACKNOWLEDGEMENTS

This dissertation was not an isolated and/or individual undertaking.

Firstly I would like to thank our Heavenly Father who gave me as well as my supervisors the strength inspiration and perseverance to make this work possible.

Secondly thank to my supervisor, Dr. Luke Sandham at the Department of Geography and Environmental Studies for hands-on advice and for keeping me motivated. Your assistance with this work was of a very high standard and I thank you. Many other people also contributed to the completion as well as the success of this project. The two persons who need to be highlighted is the former Executive Mayor of Potchefstroom, Mr. Satish Roopa. Without the support and drive of the mayor none of the projects would have been possible. The second person that was the backbone to the CCPC is Prof. Johan G. Nel from the Centre for Environmental Management. Prof. Nel was the driving force behind the whole project with passion that cannot be substituted.

Recognition and thanks to the City Council of Potchefstroom, in all the different departments. All the staff was always willing to help. Thanks to Mr. Mahesh Roopa, the Head of the Health and Environment Department for the support and making the work a bit more exiting.

Many thanks also to my wife Jo-Anne, and my Mother and Father, for constant support, motivation and prayer. Many thanks to Ben Nell, Henrico Veldman, Chirly Ings, Francois du Toit, Esme Snyman, Johan van der Berg, Christo van der Merwe, Kirsten Bosshoff, Nico van Meurs and all the others that participated in this project and who provided information and/or supported me, and for sometimes going far beyond the call of duty to obtain important data.

This is for God, my Wife, my Mother and Father, and for Ouma Grabies.

It was believed that the greatest achievement of the nineteenth-century physics was defining the concept of energy as the ability to do work. At a more practical level, achieving far greater energy efficiency, that is, doing more useful work with each kilogram of coal and each barrel of oil, may be just as important for the next generation (Ward & Mahomed, 2003)

TABLE OF CONTENTS

ABSTRACT .... A

SAMEVATTING .... B

ACKNOWLEDGEMENTS .... D

TABLE OF CONTENTS .... F

TABLE OF FIGURES I
LIST OF TABLES I

LIST OF ABBREVIATIONS AND ACRONYMS .... J

PREFACE I
Problem Statement I
Aim and objectives III
Main Aim III
Objectives III
Structure of this dissertation IV

CHAPTER 1 - LITERATURE REVIEW 1-1
The natural greenhouse effect 1-1
The enhanced greenhouse effect 1-4
General impacts of the enhanced greenhouse effect 1-6
Impacts of the enhanced greenhouse effect on South Africa 1-8
International efforts to reduce greenhouse gas emissions 1-10
The Clean Development Mechanism (CDM) 1-12
Opportunities for South Africa 1-14
Efforts by intermediate-sized African cities to reduce greenhouse gas emissions 1-22

CHAPTER 2: - MANUSCRIPT 2-1

Abstract 2-2

1. Introduction 2-3

2. Potchefstroom, a case study of local government action to reduce GHG 2-9
2.1 The city of Potchefstroom's base case energy demand and GHG footprint 2-10
2.2 Projects initiated under the Potchefstroom GHG reduction programme 2-15
2.2.1 Improvements of energy efficiencies by upgrading street lights 2-15
THOROUGHFARES 2-17
PILOT STUDY: RESIDENTIAL AREA 2-18
2.2.2 Retrofitting of the airport runway and taxiway 2-19
2.2.3 Incorporating energy efficiency specifications into the building plans of new municipal buildings 2-21
2.2.4 Recovery of methane from the sewage treatment facility 2-24
2.2.5 Carbon sequestration 2-29

2.3 Total Improvements in energy efficiencies and reduction in GHGs .. 2-30
2.4 GHG reduction projects following 2002 2-33
3. Discussion 2-34
4. Conclusion 2-35

REFERENCES 2-39

PERSONAL INTERVIEWS 2-44

APPENDIX 1: INTENDED JOURNAL GUIDELINES FOR AUTHORS 2-45
APPENDIX 2: CARBON SEQUESTRATION MODEL 2-50

TABLE OF FIGURES

Figure 1: The natural greenhouse effect (UNFCCC, 2003; IPCC, 2001) 1-3

Figure 2: The annual contribution to eCO_2 emissions in tonne 2-14

Figure 3. The emissions performance of Potchefstroom since 1995 2-32

LIST OF TABLES

Table 1: The composition of the atmosphere - main constituents and GHGs.... 1-2
Table 2 Environmental footprint of generating one kWh of electricity in South Africa 1-19
Table 3: The ecological footprint of generating electricity for an intermediate-sized South African city over the period of one year 1-20
Table 4 Environmental footprint of generating one kWh of electricity in South Africa 2-12
Table 5: The annual contribution to eCO_2 emissions by the different energy users (In tonne) 2-13
Table 6: Practicality of light emitters used for possible energy and financial saving 2-17
Table 7: Environmental and monetary aspects of retrofitting the thoroughfares.. 2-18
Table 8: Environmental and monetary aspects of retrofitting of Mieder Park .. 2-19
Table 9: Environmental and monetary aspects of upgrading the airport.......... 2-21
Table 10: Environmental and monetary aspects of construction of the new Municipal Council Building 2-24
Table 11: Old and new sewage treatment facility digestion configurations (excluding energy usage) 2-26
Table 12: Energy usage at the old and new plants 2-27
Table 13: Comparison between the old and new plants' emissions and overall eCO_2 savings 2-28
Table 14: Environmental and monetary aspects of upgrading the sewage purification works 2-28
Table 15. The total amount of eCO^2 and monetary savings achieved by the Potchefstroom GHG reduction projects 2-31

LIST OF ABBREVIATIONS AND ACRONYMS

Ar	Argon
C	Carbon
CCP	Cities for Climate Protection
CDM	Clean Development Mechanism
CERs	Certified Emission Reduction
CFC's	Chlorofluorocarbons
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COP	Conference of Parties
Cri	Colour rendering index
DBH	Diameter Breast Height
eCO_2	CO_2 equivalent
EIT	Economies in Transition
EU	European Union
GHG	Greenhouse Gas
GWP	Global Warming Potential
H_2	Water Vapour
HPS	High Pressure Sodium
ICLEI	International Council for Local Environmental Initiatives
IDP	Integrated Development Plan
IPCC	Intergovernmental Panel on Climate Change
Kg	Kilogram
kWh	Kilowatt-hour
LDCs	Least Developed Countries
MV	Mercury Vapour
N_2	Nitrogen
N_2O	Nitrous Oxide
O_2	Oxygen
O_3	Ozone
OECD	Organisation for Economic Co-operation and Development
SA	South Africa
SACAA	South African Civil Aviation Authority
SAEDES	South African Energy and Demand Efficiency Standard
SO_2	Sulphur Dioxide
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USDoE	United States Department of Energy

PREFACE

Problem Statement

Human industry and other activities, such as deforestation and the combustion of fossil fuels are emitting increasing quantities of Greenhouse Gases (GHG) into the atmosphere (Houghton, 1997; IPCC, 2001; Gilder, 2004 Pers Com). Every year these emissions add to the carbon already present in atmospheric CO_2, much of which is likely to remain there for long periods of time (Houghton, 1997; Anstuategi & Escarpa, 2001).

As a result of the accelerated rate of emissions, the total concentration of GHGs in the atmosphere has increased substantially, resulting in an anticipated increase of the average global temperature by approximately two-and-a-half degrees per century (Layman, 1997; IPCC, 2001; Lennon, 1993).

There are several real opportunities in the short-term for the South African (SA) government as well as for SA companies to participate in and benefit from the reduction of GHG emissions by the implementation of cost-effective projects and the Clean Development Meganism (CDM), led by the EU trading scheme (Bilodeau & Nel, 2002; Curnow & Goldblatt, 2004; Nel, et al. 2002). Although South Africa currently does not face Kyoto protocol reduction targets, there will likely be increasing pressure, whatever shape this may take, on South Africa, along with other industrialised developing countries, to reduce emissions (Curnow and Goldblatt, 2004).

Local governments in South Africa are increasingly recognising the critical role that energy plays in the city's economic development, social welfare and striving towards environmental sustainability (Ward & Mahomed, 2003; Bilodeau & Nel, 2002). This results in the need for local governments all over Africa as well as the rest of the world to plan and implement more sustainable approaches to their energy production and use (Curnow & Goldblatt, 2004; Nel, 2002, Ward, 2005 pers com).

Local governments are important in reducing energy use and consequently GHG emissions because they are not only big energy users and significant distributors of electricity, but are also ideally placed to influence the energy use of others, as they are the major employers, primary planners and the service providers in the city (Betsill, 2001).

At present, no research has been published on strategies, guidelines or possible approaches and results to GHG reduction by local governments in South Africa. This research paper is presented in fulfilment of this need.

Aim and objectives

Main Aim

The main aim of this dissertation is to examine opportunities for cost-effective mitigation of climate change and reduction in GHG emissions in intermediate-sized South African cities using the city of Potchefstroom as an example.

Objectives

The study has the following objectives:

- to demonstrate that intermediate-sized South African cities, such as Potchefstroom, can successfully be incorporated into global efforts to mitigate climate change;
- to demonstrate that a city's contribution to global warming can be reduced cost-effectively;
- to show that co-benefits, including economic savings and other environmental benefits, can be achieved by means of energy-use reductions;
- to illustrate the effect of employing alternative energy technology options to meet specific service demands and to substantiate that these alternative options will, compared to previous practice, result in a reduction of the quantity of GHG emitted per unit of service provided.

Structure of this dissertation

This dissertation is presented in article manuscript format. The format used is that required by the South African Geographical Journal (refer to Appendix 1) for the submission of a manuscript for publication, with a single exception: The figures and tables are inserted in the text rather than as appendices to improve readability. No reference list is provided at the end of the literature review as only one reference list is provided at the end of the manuscript.

Following the abstract and the preface, the structure of this dissertation is as follows:

- **Chapter 1 is the literature review and deals with the following issues:**
  - the natural greenhouse effect;
  - the enhanced greenhouse effect;
  - international efforts to reduce greenhouse gases;
  - efforts by intermediate-sized African cities to reduce GHG emissions

- **Chapter 2 is the manuscript and consists of the following:**
  - article abstract: presents information about the aim and results of the study;
  - introduction: presents an overview of the global warming problem, the necessity for the study, and the aim of the study;
  - Potchefstroom as a case study: presents Potchefstroom's base case energy demand and GHG footprint;
  - discussion of the projects and the opportunities to mitigate climate change in intermediate-sized African cities, using the city of Potchefstroom as an example;

- discussion of results;
- conclusion;
- references; and
- appendices.

CHAPTER 1 - LITERATURE REVIEW

The natural greenhouse effect

The earth's atmosphere is an unstable system that changes rapidly (Houghton, 1997) and is mainly composed of nitrogen (N_2), which has a volume-mixing ratio of approximately 78,1%; oxygen (O_2), with a mixing ratio of 20.9%; and argon (Ar), with a ratio of approximately 0,93%. These gases have limited interaction with the incoming short-wave radiation, and they do not interact (absorb or emit) with the thermal radiation emitted by the earth (IPCC, 2001)

There are, however, a number of trace gases, such as carbon dioxide (CO_2), methane (CH_4), water vapour (H_2), nitrous oxide (N_2O), and ozone (O_3), that do interact (absorb and emit) with infrared radiation (IPCC, 2001; Layman, 1997; Houghton, 1997; Gilder, 2004). These gases are known as the greenhouse gases (Table 1). They have a total mixing ratio in dry air of less than 0.1% by volume, and they play a fundamental role in the earth's energy budget. Additionally, water vapour (H_2O) is also present in the atmosphere and also acts as a greenhouse gas. H_2O's volume mixing ratio is highly variable but is, in general, in the order of 1% (Houghton, 1997).

Because these greenhouse gases (GHGs) are largely transparent to incoming short-wave radiation but retard outgoing long-wave radiation by absorbing and then emitting it up and downwards, they tend to raise the temperature near the

Earth's surface (Figure 1) (Hulme & Turnpenny, 2004; Houghton, 1997; IPCC, 2001). H_2O and O_3 also absorb solar short-wave radiation resulting in a further increase in atmospheric temperature.

Table 1: The composition of the atmosphere - main constituents and GHGs

Gas	**Concentration: fraction* or parts per million by volume (ppmv)**
Nitrogen (N_2)	0.781*
Oxygen (O_2)	0.209*
Argon (Ar)	0.0093
Water Vapour (H_2O)	Variable (0-0.02*)
Carbon Dioxide (CO_2)	360
Methane (CH_4)	1.8
Nitrous Oxide (N_2O)	0.3
CFC's	0.001
Ozone (O_3)	Variable (0-1,0)

Source: Houghton 1997

If the atmosphere accumulated all the retained energy or heat, then the earth's temperature would keep on rising. However, the temperature only rises until the amount of infrared or long-wave radiation leaving the Earth annually balances the amount of energy coming from the sun (short-wave radiation). The amount of thermal (long-wave) radiation emitted by the earth's surface depends on its temperature, i.e. more radiation is emitted at higher temperatures. The amount of radiation also depends on the absorptive capacity of the surface: the greater the absorption, the more the radiation (Lennon, 1993; UNFCCC, 2003).

The net result of the natural greenhouse effect is an upward transfer of infrared radiation from warmer levels near the earth's surface to colder levels at higher altitudes. The infrared radiation is effectively radiated back from an altitude with a temperature of approximately –19°C, which is in balance with the incoming short-wave solar radiation and the free space temperature. The earth's surface, on the other hand, is kept at a much higher average temperature of approximately 14°C. The atmospheric temperature without any GHGs would also be as low as -19°C, if the atmosphere only contained N_2 and O_2 (IPCC, 2001; Houghton, 1997). This natural process is essential for life on earth and is called the natural greenhouse effect.

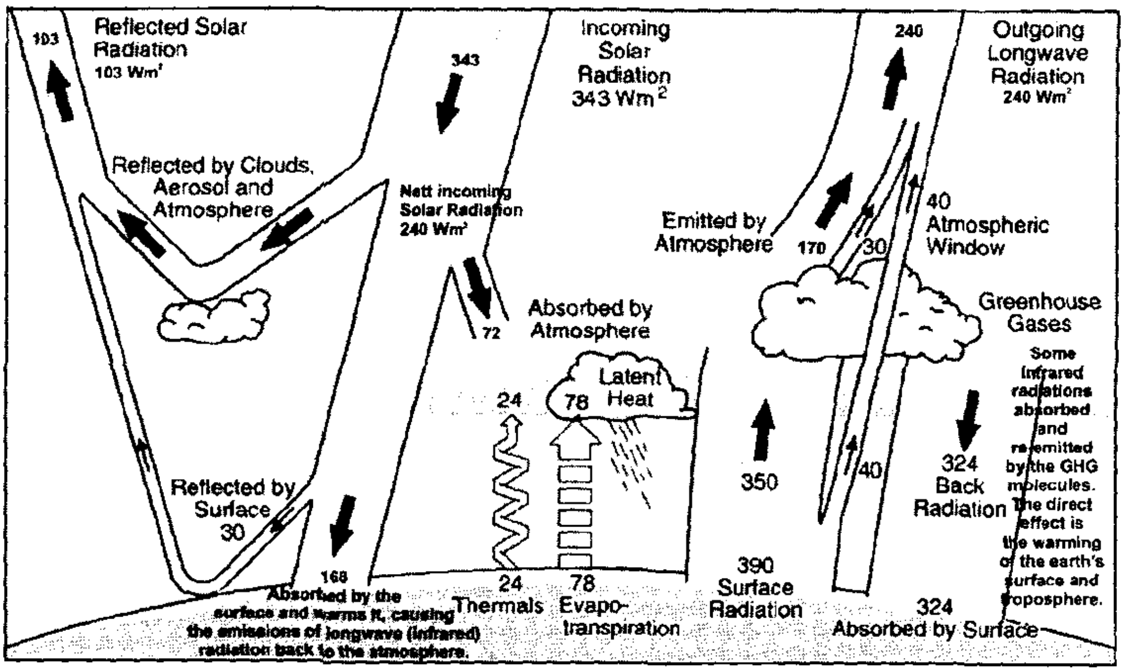

Figure 1: The natural greenhouse effect (UNFCCC, 2003; IPCC, 2001)

The enhanced greenhouse effect

Due to the population growth and the improvement of people's lifestyles, there is an increased demand for goods and services. This has resulted in an energy use expansion mainly in the developed western world, although recent increases in the demand for primary energy have also, however, occurred in the non-Western or developing countries, where escalating demands are predicted to take place mainly in the future (UNFCCC, 2003; Williams & Millington, 2004).

The major human activities resulting in emitting increasing quantities of greenhouse gasses (in particular CO_2 and CH_4) into the atmosphere are those related to fossil fuel production and burning (manufacturing, electricity generation and transportation), forestry, agriculture and waste disposal (landfills, sewage purification works and incineration) (Kates *et al.*, 1998).

Every year these emissions add a further seven thousand million tonne to the carbon already present in atmospheric CO_2, much of which is likely to remain there for a period of a hundred years or more (Gilder, 2004; Houghton, 1997). If this change were small and occurred slowly enough, adaptation may have been possible. However, according to Houghton (1997) and the IPCC Third Assessment Report (2001), the concentrations of CO_2, CH_4 and NO increased from 1800 to 2000 by 40%, 160% and 30%, respectively. The concentration of Tropospheric ozone has risen by approximately 15% of the level present in 1800. The increase of CO_2 concentration with time is, however, unlike methane (CH_4), not directly proportional to population growth. CO_2 concentrations are increasing at 0.4% per annum (IPCC, 2001).

The emissions levels are commonly measured in equivalent CO_2 (eCO_2). This is the factor that takes into account all CO_2 – and CH_4 and other GHG emissions and converts those emissions to CO_2 – or the global warming potential (GWP) thereof in comparison with CO_2. The GWP, for example, of CH_4 is 21 (21 eCO_2). In light of this fact, the long-term importance of CH_4 must not be underestimated or ignored (El-Fadel & Massoud, 2001; Curnow & Goldblatt, 2004; IPCC, 2001; Gilder, 2004).

As a result of the accelerated rate of emissions, the total concentration of GHGs in the atmosphere has increased by 30% since pre-industrial times (Anstuategi & Escarpa, 2001; Houghton, 1997, Lennon, 1993). The predicted rate of change of two-and-a-half degrees a century is probably faster than the global average temperature has changed at any time over the past ten thousand years (Layman, 1997). According to the 2001 IPCC report, the best estimate is approximately 0.6°C since the late 19th century. The warming rate since 1976 (0,17°C/decade) has been slightly higher than the 0,14°C/decade rate that occurred during the period 1910 to 1945.

As there is an approximate five to six degrees difference in the global average temperature between the coldest period of an ice age to the warmest temperature between the ice ages, it is clear that a few degrees in global average temperature can present a big change in climate.

Future projections are that, in the absence of controlling factors, the rate of increase in atmospheric carbon dioxide will accelerate and that atmospheric concentration will double from its pre-industrial value well within the next hundred years (Anstuategi & Escarpa, 2001). No significant changes in levels of atmospheric water vapour have yet been confidently observed, but it is believed that with the increased temperature, the amount of water vapour in the atmosphere also increases, resulting in accelerating the greenhouse effect even more (IPCC, 2001 & Houghton, 1997).

General impacts of the enhanced greenhouse effect

According to Curnow and Goldblatt (2004) and the IPCC report (2001), it is predicted that the increased concentration of GHGs will produce changes to the global climate, including changes in the surface temperature. As the climate warms, there will be a decrease in the snow cover and sea-ice extends in the northern hemisphere. The global average mean water vapour evaporation and precipitation may increase. Climate change may may also lead to an increase in the mean precipitation in tropical areas and a decrease in precipitation in most of the sub-tropical areas. In the high latitudes the mean precipitation may increase. The intensity of rainfall events may also increase (Meadows & Hoffman, 2004).

As the increased temperature and evaporation in mid-continental areas during summer will not be balanced by increases in precipitation, general drying of these areas is expected. With an increase in the mean surface air temperature there will be more frequent extreme high maximum temperatures and less frequent extreme low minimum temperatures.

These climatic changes will lead to lagged effects, such as changes in hydrological and vegetation patterns, damage to urban infrastructure, and sea level rise[1] due to the decrease in snow cover and sea-ice extend in the northern hemisphere, which will eventually inundate infrastructure and settlements in many coastal cities (Hulme & Turnpenny, 2004; Houghton, 1997; IPCC, 2001).

Because over centuries human communities have adapted their lives and activities to the present climate, most changes in climate will tend to produce an adverse impact. It is relatively easy to consider the effects of a particular change (sea level rise or diminished water resources) supposing nothing else changes. Some adaptation to small changes may, for some ecosystems and human communities, be relatively easy to achieve; however, adaptation may be very difficult and very costly or even impossible.

[1] May be a much as 0.9m by 2100 (DEAT,2006).

Impacts of the enhanced greenhouse effect on South Africa

At present, Africa accounts for about 10% of GHG global emissions (Gwebu, 2002), and South Africa is regarded as the 14^{th} worst – and per capita the seventh-worst[2] – in the world with regard to carbon emissions. Although South Africa is only responsible for 0,9% of the world's gross domestic product, this country is responsible for between 1.2% and 2% of the globe's GHG emissions (Spalding-Fecher & Immink, 2005;). It is, however, believed that when the South African economy as well as the African continent's economies begin to grow and the development process becomes more sophisticated, in terms of both technological input and the supporting service infrastructure, GHG emissions are expected to increase correspondingly (Gwebu, 2002). While African countries are not the major contributors to the build-up of CO_2 in the atmosphere individually, the increased concentration of greenhouse gases in the atmosphere remains a serious trans-boundary problem, with worldwide negative consequences to climate.

The first national report on climate change, submitted by the South African Government under the United Nations Framework Convention on Climate Change (UNFCCC), the international treaty which along with the Kyoto Protocol represents the present structure for dealing with the global confrontation of climate change, states that climate change may have considerable effects on

[2] *Equivalent emission rate per person in SA is 10 tonne of CO_2/person/a. The global average is 7 tonne of CO_2/person/a (DEAT, 2006).*

almost all sectors of South African society and the economy (Curnow & Goldblatt, 2004; Worthington & Sherman, 2002).

It is expected that in South Africa there will be a reduction in the current rainfall by between 5% and 10% for summer rainfall regions and a subsequent increase in water scarcity, increased incidents of flood and drought, extension of the malaria-prone areas, and greater risk of bilharzias. A marginal increase in early rainfall is predicted for the winter rainfall region of the country (Meadows & Hoffman, 2004); however, it is expected that there will be a drying in the south-western Cape (Hewitson, 2005). General aridification is also expected, affecting optimal areas for forestry as well as decreasing maize production, coupled with an increase in pests and diseases in agricultural production (Curnow & Goldblatt, 2004; Worthington & Sherman, 2002; Lennon, 1993).

One of the greatest challenges facing national government, local governments, and other policymakers in dealing with the global problem of climate change is developing appropriate responses that work in the direction of a long-term goal, while still providing enough policy assurance and flexibility in the short- term to enable government and other policymakers to adapt and reorganise at minimal cost (Bilodeau & Nel, 2002). The short-term business costs and planning that are required to meet the long-term goal of significantly reducing global emissions of greenhouse gases are what have made ratification of the Kyoto Protocol such a contentious political issue (Curnow & Goldblatt, 2004; Nel, 2002).

In reality, climate change, along with other economic and environmental issues, presents both risks and opportunities for large and even smaller or intermediate-sized local governments to manage.

International efforts to reduce greenhouse gas emissions

On 11 December 1997 the third conference of the parties (COP3) to the United Nations Framework Convention on Climate Change was held in Kyoto, Japan. With the Kyoto Protocol, 160 countries reached an agreement whereby the world's developed countries pledged to collectively reduce their GHG emissions to an average of at least 5,2% below 1990 levels in the commitment period 2008 to 2012 (Worthington & Sherman, 2002; UNFCCC, 1997; UNFCCC, 2003). Only parties to the United Nations Framework Convention on Climate Change (UNFCCC) that have also become parties to the Protocol[3], however, will be bound by the Protocol's commitments, once it comes into force.

Each party included in Annex I, according to Article 3 of the Kyoto Protocol (1997), shall by 2005 have made comprehensible progress in achieving its commitments. The UNFCCC (hereinafter referred to as 'the Convention') divides countries into three main groups according to differing commitments.

[3] By ratifying, accepting, approving, or acceding to it.

Annex I parties include the industrialised countries that were members of the Organisation for Economic Co-operation and Development (OECD) in 1992 as well as the countries with economies in transition (EIT).

Annex II parties consist of the OECD members of Annex I but not the EIT parties. Annex II parties are required to provide financial resources to enable developing countries to undertake emission reduction activities under the Convention and to help them adapt to adverse effects of climate change.

The third group (non-Annex I parties) consists of 145 countries, of which 48 countries are defined as least developed countries (LDCs) by the United Nations. The non-Annex I parties are given special consideration under the Convention on account of their limited capacity to respond to climate change and adapt to its adverse affects.

All Annex I parties that have ratified, accepted, approved or acceded to the Convention are subject to general obligations to respond to climate change. They concur to compile an inventory of their GHG emissions and submit reports, known as national communications, on the actions they are taking to put the Convention into practice. To focus such actions, they must prepare national programmes that include climate change mitigation measures and provisions for developing and transferring environmentally-friendly technologies. They are also responsible for managing their carbon sinks[4] sustainably, to engage in climate research, and to promote education relating to climate change and mitigation.

According to article 2 of the Kyoto Protocol (1997), each party included in Annex I must implement and further elaborate policies and measures in accordance with its national circumstances, such as:

- energy efficiency programmes;
- protection and enhancement of their carbon sinks and reservoirs;
- promotion of sustainable forms of agriculture;
- increased use, research, promotion and development of new and renewable forms of energy and CO_2 sequestration technologies;
- measures to limit and/or reduce emissions of GHG not controlled by the Montreal Protocol in the transport sector; and
- limitation and/or reduction of CH_4 emissions through recovery and use in waste management.

According to the UNFCCC (2003) the Kyoto Protocol also established an international greenhouse gas emissions trading regime.

The Clean Development Mechanism (CDM)

Under the Kyoto Protocol, a Clean Development Mechanism (CDM) was developed. The CDM defined in article 12 of the Kyoto Protocol, provides for Annex I parties to implement project activities that reduce emissions in non-Annex I parties (countries) in return for certified emission reductions (CERs).

[4] A general term for forests and other ecosystems that can remove more greenhouse gases from the atmosphere than they emit.

Countries similar to South Africa can use the CERs produced by such projects' activities in attaining fulfilment of their quantified emission limitation and reduction commitments under article 3 of the Convention (UNFCCC, 2003; Curnow and Goldblatt, 2004).

Article 12 also stresses that such projects are also in place to assist the developing countries (non-Annex I countries) to host parties in achieving sustainable development and in contributing to the ultimate objective[5] of the Convention by implementing the actions as stated in its article 2, listed above.

The current modalities and procedures for the CDM focus on activities that reduce GHG emissions. The rulebook for the CDM, set forth in the Marrakesh Accord[6], sets out detailed rules for the implementation of the CDM. Under the Marrakesh Accord, Annex I parties are not allowed to use CERs generated through nuclear facilities to meet their emission targets.

A number of projects whereby Annex I parties are performing emission-reduction activities in developing (non-Annex I) countries to count toward the reductions achieved against their own targets are already being implemented.

[5] Stabilising atmospheric concentrations of GHGs at levels that would prevent 'dangerous' human interference with the climate system.

[6] Culminated in COP 7.

According to the European Union (EU) emissions trading scheme, companies and governments that do not use all their allocated allowances are able to sell them to companies that cannot keep their emissions within their allocated allowances, thereby enabling reductions to be made where it is cheapest to do so (Curnow and Goldblatt, 2004; Hulme and Turnpenny, 2004).

In summary, the Convention (UNFCCC) serves as a broad policy instrument for the investigation and management of global climate change, particularly its nature and properties, directional characteristics and probable consequences on both managed and natural ecosystems (Gwebu, 2002). Notwithstanding the significance of the Convention, the successful resolution of the problem posed by climatic change due to GHG emissions will depend ultimately on individual countries perceptions, policies and principles on how best to respond to climate change issues (Kates *et al.*, 1098). The main motivation for this statement is that while the global warming issue is a global concern, the sources of GHG emissions are very local.

Opportunities for South Africa

For South Africa (non-Annex I), the question is where do South African cities and towns fit into the total scheme of global warming reduction events.

Under the EU trading scheme, European companies will be able to use credits from emission reduction projects around the world toward meeting their allowance obligations.

Recent analyses, according to Curnow and Goldblatt (2004), estimate that the global transactions volume will be around 100 million tonne of CO_2-

equivalents (eCO_2), with a value of approximately £400 million[7] (pound sterling), in the commencement years of the trading scheme (started in 2004), with just over half the total volume coming from CDM projects. The average price per tonne of eCO_2 ranges from £3.50 to £7.00 (pounds sterling) (Gilder, 2005).

The South African Government is aware of the potential for the CDM in South Africa. The primary role for national and local government is to establish the necessary institutional and legal arrangements to allow CDM projects to occur. Beyond question are the several real opportunities in the short-term for the South African government and South African companies to participate in and benefit from the CDM and the emerging international carbon markets led by the EU trading scheme.

Although South Africa currently does not face Kyoto targets (Spalding-Fecher & Immink, 2005), there is likely to be increasing pressure on South Africa, along with other industrialised developing countries (non-Annex I), to reduce emissions, whatever shape such commitment may take. Pressure on local government (whether large or intermediate-sized) in South Africa may also come from national government (Borchers, 2003; Curnow & Goldblatt, 2004; Bilodeau & Nel 2002). While there is currently no reporting requirement on local government

[7] £1 = R12.89 at the time of writing (March 2006)
£1 = $6.80 At the time of writing (March 2006)

GHG emissions, there is likely to be increasing shareholder and public scrutiny of the emissions profiles of local governments in South Africa.

Betsill (2002) and Bulkeley (2000) state that, although the political emphasis has primarily been on developing an international response to global warming through the negotiation of the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, countries will not be able to meet the commitments contained in these agreements without the assistance of city governments. Currently, 34% of people in Africa live in cities, but these cities are accountable for more than 60% of its GDP (Ward, 2003). Although cities are immense consumers, they also have the authority and liability to initiate and administer a much more sustainable development path (Bilodeau & Nel, 2002).

South Africa does not have a dedicated policy to respond to climate change (Gilder, 2005). However, the global climatic impacts from the energy sector, which is a large source of greenhouse gas emissions, is acknowledged by the South African Government.

The electric power sector has the potential to produce and deliver electricity essentially free of GHG emissions, primarily CO_2. Currently electricity is generated worldwide predominantly from fossil fuels, with coal being the dominant fuel choice[8] (Portelli, 2002; Sullivan, 1991; Spalding-Fecher & Immink, 2005). Non-CO_2 emitting electricity generating technologies based on nuclear reactors, renewable sources and geothermal energy are commercially available and, technically, could supply the necessary energy for the world's needs (National Research Council, 1991). Because of price, other possible environmental, health and safety impacts, and the deployment of these technologies on a large or even worldwide scale, implementation seems very unlikely to be feasible at this stage. Therefore, the importance of using the current energy sources much more effectively cannot be overstressed (Layman, 1997; Lennon, 1993).

Local governments in South Africa are increasingly recognising the critical role that energy plays in a city's economic development, social welfare and striving towards environmental sustainability (Ward & Mahomed, 2003; Williams & Millington, 2004). This results in the need for local governments all over Africa and the rest of the world to plan and implement more sustainable approaches to their energy production and use.

A major obstacle, however, to achieving a more sustainable city system lies in the way energy is perceived. The current situation in African cities is that energy consumption, rather than the level of energy services, is seen as the indicator of

[8] No less than 92,8% of South African electricity generation is coal-based (Spalding-Fecher & Immink, 2005)

development (Ward & Mahomed, 2003). By taking energy consumption as the measure of development, energy providers and planners are often concerned simply with ever-increasing fuel and electricity supplies based on existing patterns of energy use, rather than with identifying and implementing sustainable energy services to satisfy human needs. By doing so, energy providers can provide energy to more people, while at the same time maintaining or even reducing the GHG emissions of providing the energy.

According to the United Nations Conference on Environment and Development (1992), local authorities construct, operate and maintain economic, social and environmental infrastructure, oversee planning processes, establish local environmental policies and regulations, and assist in implementing national and sub-national environmental policies. However, in South Africa, as with most developing country's cities, local governments lack the institutional capacity to carry out effective environmental planning and management and to permanently provide effective urban services and carry out the necessary environmental duties (Nel, 2002; Gwebu, 2002).

The contributions of current resource needs and pollution levels, combined with rapid growth rates in developing countries, to the GHG emissions and waste generation capacities of cities are currently unsustainable when compared to the declining capability of the natural world to support them (Nel *et al.*, 2002). The increases in energy needs will have further devastating environmental impacts as illustrated by the ecological footprint[9] of generating one kWh of electricity in South Africa (Eskom, 2000).

Table 2 Environmental footprint of generating one kWh of electricity in South Africa

Element	**Unit**	**Footprint Impact**
Water usage	Litres	1.21
Coal usage	Kilograms	0.49
Ash produced	Kilograms	0.13
Ash emitted	Kilograms	0.00035
SO_2 emissions	Kilograms	0.00795
NO_X emissions	Kilograms	0.00356
CO_2 emissions	Kilograms	1.135

(Eskom, 2000; ICLEI, 2002)

The ecological footprint for the generation and supply of sufficient electricity for one year to an intermediate-sized South African city (size of Potchefstroom) is illustrated in Table 3.

[9] Ecological footprint is the sum of those areas (ecologically productive space) we need to sustain the lifestyle of each person (SA average - 4.28ha; international average - 1.9ha).

Table 3: The ecological footprint of generating electricity for an intermediate-sized South African city over the period of one year

Element	**Footprint**
Water usage (litres)	18 051 969
Coal usage (kg)	7 310 301
Ash produced (kg)	1 939 467
Ash emitted (kg)	5 221
SO_2 emissions (kg)	118 605
NO_X emissions (kg)	53 111
CO_2 emissions (kg)	16 938 267

The quality of life of people living in urban areas deteriorates significantly as a result of the unsustainable relationship between the city and the general state of the environment as indicated in Table 3. Cities in developing countries are characterised by poor air-quality profiles that negatively impact on both the quality of life of their citizens and investor confidence (Bilodeau & Nel, 2002; Nel, 2002)

It is increasingly acknowledged that city administrations need to become as innovative as their counterparts in the private sector to pro-actively reduce their ecological footprint, to improve the quality of life of their citizens, and to grow their local economic base.

Local governments, therefore, are challenged to acknowledge and address their contributions to the long-term risks posed by climate change as well as to realise the multiple benefits of cleaner and more efficient energy consumption practices. Through their roles and decision-making powers, local governments directly influence and control many activities that generate GHG emissions (Nel *et al.*, 2002; Bilodeau & Nel, 2002; Ho Kim Hin *et al.*, 1997). If the issue of climate change is to be addressed successfully, then the reduction of GHG emissions must also be addressed at local level.

Improving the efficiency of energy use should be encouraged by technical development and government incentive, since not only does it reduce all emissions, including greenhouse gases from fossil fuel, but it also extends the life of the world's resources (Lennon, 1993). The biggest challenge, however, is to get mayors and councillors committed to sustainability issues in view of other pressing socio-political and socio-economic issues and priorities (Bilodeau & Nel, 2002; Nel, 2002; Nel *et al., 2002*).

One possible strategy to commit decision makers at local level in the developing world to support sustainability programmes is to combine programmes that aim to achieve improvements in environmental management performance with opportunities to save costs, create jobs, transfer skills and reduce poverty (Nel, 2002; Ward & Mahomed, 2003).

Efforts by intermediate-sized African cities to reduce greenhouse gas emissions

Climate change is generally framed as a global problem with future impacts. As a result, city officials often have little understanding of how they contribute to the problem of global climate change and how they may be affected by the impacts of climate change in the future (Betsill, 2001).

However, Bulkeley (2000) states that there is a crucial role for considering the local politics of global warming, because the majority of climate change politics may have to devolve to the local level if policies are to become effective in the informal institutional dynamics of individuals and households. As much as the CDM presents real-time commercial opportunities for South African local governments in the short term, there is a growing recognition among local governments in South Africa for longer term planning and decision making beyond Kyoto. Early experience can place local governments ahead of competitors in developing mitigation projects and measuring their levels of emissions, thereby better preparing them for future international frameworks and domestic policies (Curnow & Goldblatt, 2004).

Because national government is currently busy developing its National Climate Change Response Strategy, it is timely for local governments in South Africa, whether large, intermediate or small, to be giving greater attention to what the risks and opportunities are with regard to climate change mitigation and adaptation in order to influence policy-making. This will assist South Africa in being able to accept its reasonable share in the following phase of international action on climate change (Curnow & Goldblatt, 2004).

The Energy White Paper's goals include an integrated resource planning approach to energy and the management of health and environmental impacts of energy generation. Notwithstanding this and the potential for very substantial energy and GHG savings in a number of areas of local authority operations, a comprehensive literature search carried out indicates that recent literature has only attempted to verify several of the projections on climate change that have been detailed by the IPCC reports and that there is currently no published research on strategy or guidelines for implementing projects to achieve GHG reductions by local governments in South Africa[10].

Borchers (2003) states that the international investment market is increasingly discerning and is looking at energy efficiency as an important component of investment decisions. However, there are a lack of policies, regulations and incentives promoting energy efficiency in local authority activities.

Darier and Schule. (1999) and Borchers (2003) state that the question 'What kind of climate protection action is recommended for local governments, and what kinds of obstacles and responsibilities for climate protection have been identified?' has not yet been answered. They further state that access to

[10] Desktop study including internet searches, articles, book searches, and previous dissertations, as well as interviews with various role players.

information about energy efficiency and other ways to reduce GHGs is relatively poor and that little incentive to be more energy efficient has occurred in South Africa because of the cheapness of electricity. No comprehensive study on the energy saving potential in the local authorities is available or has been carried out (Borchers, 2003).

In South Africa, as is the case with most other African countries, enhanced research capacity is still required to develop coherent environmental policies, accurate national inventories of anthropogenic sources and emissions of GHGs, mitigation measures, and the effective monitoring of compliance so as to fulfil the objectives of the conventions aimed at minimising global warming (Gwebu, 2002).

It is the goal of this study to assess the possibility for and obstacles to the mitigation of GHG emissions for a developing, intermediate-sized South African city such as Potchefstroom. The aim is further to successfully address the reduction of GHG emissions by linking the below-mentioned preferred response to issues (e.g. *air quality, tree planting, street lighting) already on the local* agenda and to demonstrate that it is financially practicable to implement such projects. This study endeavours to show that, although from a rational choice perspective, it is not logically correct for a local government to invest in the mitigation of its GHG emissions, cities would be able to achieve co-benefits, such as economic savings and other environmental benefits, in addition to the climate-related benefits.

The study also identifies alternative energy technology options to meet specific service demands while reducing the quantity of GHG emitted per unit of service provided, compared to previous practice.

CHAPTER 2: - MANUSCRIPT

THE IMPLEMENTATION OF URBAN GREENING PROJECTS FOR ENERGY EFFICIENCY AND GREENHOUSE GAS REDUCTIONS IN POTCHEFSTROOM, SOUTH AFRICA

G. NEL

School of Geography and Environmental Studies
North-West University
Potchefstroom
2520

THE IMPLEMENTATION OF URBAN GREENING PROJECTS FOR ENERGY EFFICIENCY AND GREENHOUSE GAS REDUCTIONS IN POTCHEFSTROOM, SOUTH AFRICA

Abstract

As a result of the accelerated rate of Greenhouse Gas (GHG) emissions, the total concentration of GHGs in the atmosphere has increased by 30% since pre-industrial times, which may result in elevated average global temperatures, changes in regional precipitation rates, increased incidence and intensity of extreme weather events, and a rise in the sea level.

Although there is a substantial amount of research concerning global warming, greenhouse gases and policy initiatives, there is still a gap in the understanding of how local governments in Africa can contribute to reducing greenhouse gas emissions at a local level to contribute to addressing this global issue.

This study examines the opportunities and challenges for intermediate-sized African cities to cost-effectively reduce their GHG emissions associated with the use of energy, methane recovery and utilisation, and CO_2 sequestration, using the city of Potchefstroom as a case study. This city's urban greening projects were carried out to meet specific service demands in the respective market sectors, while the application of technology was accompanied by significant reductions in the quantity of GHG emitted. A total reduction in GHG emissions of 44.84% was achieved in Potchefstroom, as a result of the implementation of the GHG reduction projects.

1. Introduction

According to Williams & Millington (2004), the increase of the world population and the improvement of lifestyle as a result of the Industrial Revolution, has resulted in an increase of energy use, deforestation, waste generation, combustion of fossil fuels and a subsequent increase in the quantities of Greenhouse Gas (GHG) emissions, in particular CO_2 and CH_4, into the atmosphere.

This increase in the amount of GHGs since pre-industrial times may be as much as 30% (Anstuategi & Escarpa, 2001; Houghton, 1997, Lennon, 1993), which will result in an anticipated increase in the average global temperature of approximately two and a half degrees per century (IPCC, 2001; Layman, 1997; Lennon, 1993). This increase in the average global temperature may result in numerous climatic changes and subsequent lagged affects (Hulme & Turnpenny, 2004; IPCC, 2001).

At present, South Africa is responsible for 0,9% of the world's gross domestic product but is responsible for between 1.2% and 2% of the globe's GHG emissions (Spalding-Fecher & Immink, 2005) and is regarded as one of the 10 largest carbon emitters per capita in the world (Gwebu, 2002). It can also be expected that with future development and economic growth, in terms of both technological input and the supporting service infrastructure, the GHG emissions will increase correspondingly (Worthington & Sherman, 2002).

South Africa's first national report on climate change, which along with the Kyoto Protocol constitutes the current framework for dealing with the global challenge of climate change, states that climate change may have significant effects on almost all sectors of South African society and the economy (Curnow & Goldblatt, 2004; Worthington & Sherman, 2002).

The Clean Development Mechanism (CDM) that was developed under the Kyoto Protocol provides for Annex I parties to implement project activities that reduce emissions in non-Annex I parties (countries) (such as South Africa) in return for certified emission reductions (CERs). Annex I parties can use the CERs generated by such projects' activities in achieving compliance with their quantified emission limitation and reduction commitments under article 3 of the United Nations Framework Convention on Climate Change (FCCC) (Curnow & Goldblatt, 2004; UNFCCC, 2003).

Despite the significance of the Convention and the CDM, as emphasised by numerous researchers, the successful alleviation of the predicament posed by global warming will ultimately depend on individual countries' perceptions, policies and principles on how best to respond to climate change issues (Kates *et al.*, 1998). This is because global warming is a global concern, but the sources of GHG emissions are local and must therefore begin to be addressed at a local level (Betsill, 2002; Bulkeley, 2000). "Think global, act local" links to this concept.

With increasing pressure on South Africa (SA) to reduce its GHG emissions (Spalding-Fecher & Immink, 2005) and with the South African government well aware of the potential of the CDM for SA, the position of South African cities and towns in the total scheme of global warming reduction events needs to be considered. Betsill (2001) also states that municipal governments need to be incorporated into international endeavours to mitigate climate change. Therefore, the most important role for national and local governments is to establish the necessary strategies to allow for GHG reduction projects in order to benefit directly from GHG reductions and indirectly from the CDM. Local government in particular needs to realise that there are numerous real opportunities by which South Africa can benefit from energy efficient consumption practices (Curnow & Goldblatt, 2004; Gwebu, 2002). They must therefore, acknowledge and address their contributions to the long-term risks posed by climate change (Bilodeau & Nel, 2002; Nel *et al.*, 2002; Ho Kim Hin *et al.*, 1997). Although the political emphasis in South Africa is primarily focused on developing a response to global warming through negotiation of the United Nations Framework Convention on Climate Change and the Kyoto Protocol, Betsill (2001) states that countries will not be able to meet the commitments contained in these agreements without the assistance of local governments.

According to Ward (2003), 34% of people in Africa live in cities, but those cities are responsible for more than 60% of its GDP. This means that cities, while they are great consumers, can therefore also play an important role in the reduction of energy use and subsequent GHG emissions. Local governments, as primary planners and major employers have the power and responsibility to initiate and manage a much more sustainable development path, as they have control over their own energy use and are ideally placed to influence the energy use of others. (Williams & Millington, 2004; Ward & Mahomed, 2003; Bilodeau & Nel, 2002; Betsill, 2001). However, in South African cities, as in most developing countries' cities, local governments lack the institutional capacity to carry out effective environmental planning and management (Gwebu, 2002; Nel, 2002).

Because of cost, other possible environmental, health and safety impacts, and the fact that the deployment of renewable and other energy technologies on a large or even worldwide scale seems very unlikely to be feasible at this stage, the importance of using current energy sources more effectively as well as the utilisation of current greenhouse gas emissions (for example CH_4) for the production of energy must be seen as some of the best practical methods to reduce GHG emissions (Williams & Millington, 2004; Ward & Mahomed, 2003; Bilodeau & Nel, 2002; Worthington & Sherman, 2002; Ho Kim Hin *et al.*, 1997).

While there is currently no requirement for local governments to report on GHG emissions, pressure on national government, and therefore also on local governments, to reduce GHG emissions is being increased, and there is likely to be increasing shareholder and public scrutiny of the profiles of local governments' emissions (Curnow & Goldblatt, 2004; Borchers, 2003; Bilodeau & Nel 2002). It is therefore sensible for local government in South Africa to assess the possible risks and opportunities for climate change mitigation to ensure that it will be able to make the appropriate contribution in order to reach the reduction targets (Curnow & Goldblatt, 2004).

There are, however, a number of reasons why municipal governments may be hesitant to take action on the issue of global warming. These include, but are not limited to, the perception that, firstly, it makes little sense for local governments to expend resources to control their GHG emissions, as it is not clear that action to control emissions in one place will have any measurable effect on the overall threat of global climate change. Secondly, the perception is that controlling local emissions will do little to protect a particular community from the potentially adverse effects of climate change (Betsill, 2001).

As part of this study, a comprehensive literature research was performed to identify possible strategies or guidelines for implementing projects to achieve GHG reductions by local governments in SA. This search found that there is currently no strategy or guidelines available for this purpose and that recent literature only attempted to verify several of the projections on climate change that have been detailed by the IPCC report.

This is confirmed by Borchers (2003), Gwebu (2002) and Darier and Schule (1999) who stated that no comprehensive study on the energy saving potential in the local authority areas is available or has been carried out and that access to information about energy efficiency and possible mitigation measures to reduce GHGs in local authority areas is relatively poor.

It is the goal of this paper to confirm the necessity for cost-effective reduction of GHG emissions in intermediate-sized South African cities and to demonstrate that these cities can successfully be incorporated into global efforts to mitigate climate change. This paper will further substantiate that this objective can be achieved by linking the reduction of GHG emissions to issues already present on the local agenda. The paper will demonstrate the economic feasibility of implementing such projects. Although it apparently makes little economic sense for local governments in South Africa to allocate funds to mitigate its GHG emissions, this study will attempt to prove that cities would be able to achieve co-benefits, such as economic savings and other environmental benefits in addition to the climate-related benefits.

In this paper the opportunities and challenges for intermediate-sized African cities to cost-effectively reduce their GHG emissions associated with sewage treatment and to use energy in different municipal sectors will be discussed by explaining the efforts and achievements of the city of Potchefstroom.

2. Potchefstroom, a case study of local government action to reduce GHG

Potchefstroom is situated approximately 120 km south-west of Johannesburg in the North-West Province. In 2001, the Potchefstroom Municipality had a population of approximately 260 000 people of which 35% were unemployed (Statistics SA, 2001)

In 2001, Potchefstroom elected to participate in the Cities for Climate Protection Campaign (CCPC), a programme of the International Council for Local Environmental Initiatives (ICLEI, n.d.). This programme is a performance-oriented campaign that offers local governments a framework for developing a strategic agenda to reduce their GHG and air pollution emissions, with the added benefit of improving living conditions for local communities. The CCPC programme provides local governments with a milestone framework, helping them to identify their GHG emissions, set reduction targets and develop action plans to reach their targets. In addition, ICLEI also provides the necessary capital for members[11] to install certain action plans in their local municipalities. These funds are made available to local municipalities after review and acceptance of their action plans.

[11] Any municipality can become a member of ICLEI. In order to be considered for funds, the member municipalities need to be actively involved with yearly ICLEI activities.

The CCPC milestones are set in order to assist local governments to comply with the commitment made during the Kyoto Protocol, namely to collectively reduce the average yearly GHG emissions by at least 5,2% below 1990 (or baseline year) levels in the commitment period 2008-2012 (Worthington & Sherman, 2002; UNFCCC, 1997; UNFCCC, 2003). The CCP milestones that were adopted by Potchefstroom are:

- Conduct a GHG emissions inventory of current council and community activities and a forecast of GHG emissions growth in the future.
- Establish a GHG emissions reduction goal.
- Develop a local action plan.
- Implement the local action plan.
- Monitor and report on the implementation of the local action plan.

Since the implementation, monitoring and reporting are longer term functions of the council, they fall outside of the scope of this article, hence only the first three milestones are discussed here.

2.1 The city of Potchefstroom's base case energy demand and GHG footprint

The purpose of the local inventory of GHG emissions for local governments is to identify and quantify the most important sources of GHG emissions within the local government and to identify the most effective opportunities and strategies for reducing those emissions (Kates *et al.*, 1998). Emissions levels are commonly measured in equivalent CO_2 (eCO_2). This is the factor that takes into account

CO_2, N_2O, CH_4 and other GHG emissions and converts those emissions to the global warming potential (GWP) of CO_2.

Estimating the amount of eCO_2 in a city is a difficult concept due to the spatio-temporal differential between emissions and the point of final utilisation. This can be illustrated by the difference between the burning of fossil fuels in townships and electricity and power plant emissions. Although all GHG emissions could be linked to final consumption behaviour, the extent to which such a principle can be functional is a critical predicament in the methodology of local emission inventories (Kates *et al.*, 1998). The inventory for each local government must address the problem of how to assign emissions that are produced outside of the local governmental area, for example, the amounts of hydrocarbons purchased outside the municipal boundary and used within, and vice versa. For this reason it was decided to focus only on those GHG emissions that are a direct result of activities participated in or services provided by the local government and not to focus on the city as a whole. Moreover, this is a logical place to begin, given the council's role as both producer and regulator of GHG emissions.

As a result of the insufficient quality of energy use input data for Potchefstroom, the baseline year (a basis for comparison, to determine the city's success regarding the yearly reduction in eCO_2) was determined by the availability as well as the quality of energy data for previous years. Due to a lack of reliable information prior to 1995, this year was selected as the baseline year for the Potchefstroom inventory.

The primary plan of the local government was to reduce emissions by implementing programmes to achieve better energy efficiency and consumption practices. The second plan was to reduce emissions at source, and the third plan was to include the calculation of sequestrated CO_2 in newly planted and existing trees.

The total energy usage by the Council was calculated by using Eskom electricity invoices and the Council's records of fossil fuel (hydrocarbons) consumption by all of the movable assets. The number of kilowatt-hours (kWh) was converted to eCO_2 emissions by using the CCP software (Torrie Smith Associates, 1997) and was verified by using the Eskom conversion rates and resource use rates (Table 4). This table demonstrates the environmental footprint for generating one kWh of electricity (e.g. the generation of one kWh will use 1.21 litres of water and will emit 0.35 grams of ash).

Table 4 Environmental footprint of generating one kWh of electricity in South Africa

Element	**Unit**	**Conversion rate**
Water usage	Litres	1.21
Coal usage	Kilograms	0.49
Ash produced	Grams	130
Ash emitted	Grams	0.35
SO_2 emissions	Grams	7.95
NOX emissions	Grams	3.56
CO_2 emissions	Kilograms	0.85

(Eskom, 2000)

The litres of fuel consumed were converted to eCO_2 emissions by the CCP software. The total emissions by all of the Council's facilities for the baseline year 1995 were 31 714 tonne of eCO_2. The breakdown of the different contributors is reflected in Table 5.

Table 5: The annual contribution to eCO_2 emissions by the different energy users (In tonne)

Year	Electricity usage	Petrol used	Diesel used	Digestion at Sewerage Purification Works	Incineration at Sewerage Purification Works	Total eCO_2 emissions
1995	16 938	594	801	13 095	287	31 715
1996	18 626	556	815	13 753	302	34 052
1997	19 261	667	854	14 390	316	35 488
1998	17 899	687	872	15 048	331	34 837
1999	16 856	670	852	15 706	345	34 429
2000	16 811	679	866	16 364	359	35 079
2001	16 453	685	876	17 021	374	35 409
Total	**122 844**	**4 538**	**5 936**	**105 377**	**2 314**	**241 009**

(Calculated by Nel, 2002)

As is evident from Table 5 as well as Figure 2, the two dominant emission contributors in 1995 were the electricity usage of the different facilities owned by the Council and the eCO_2 emissions from the sewage purification works. In 2001, the biggest GHG emissions came from the sewage purification works. The largest user of electricity, and hence the largest emitter as a result of energy usage, in Potchefstroom was street lighting with an energy usage of between 5 706 188 kWh and 5 882 049 kWh per year.

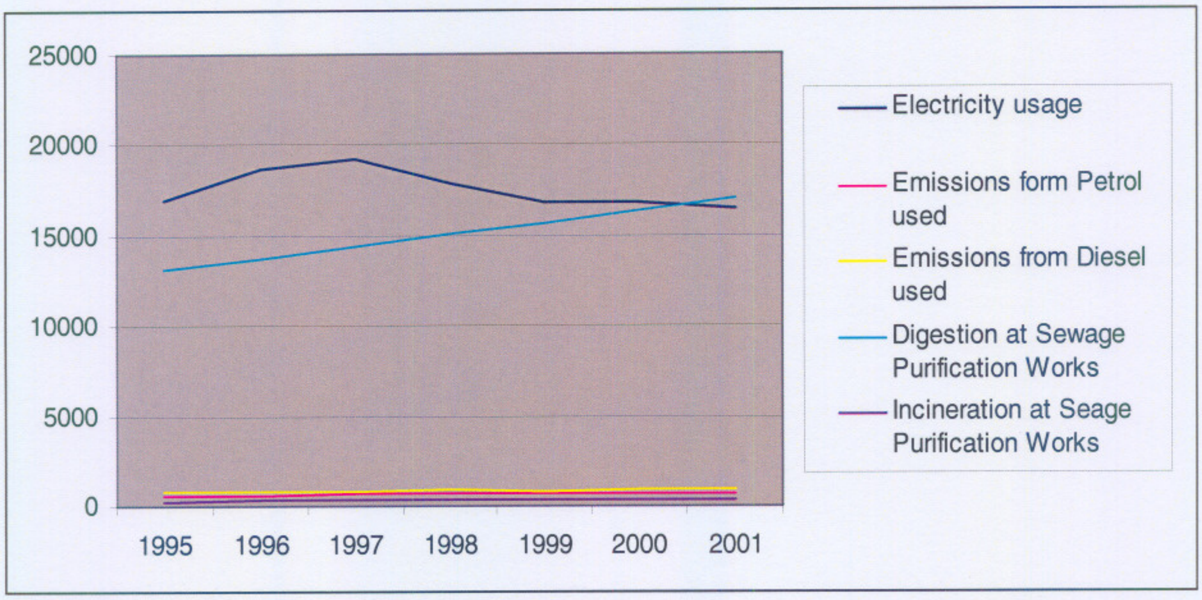

Figure 2: The annual contribution to eCO_2 emissions in tonne

Due to population growth, all of the GHG emissions for the different municipal sectors increased from 1995 to 2001 (Figure 2). The GHG emissions due to electricity usage, however, started to decrease from 1998. This is because, since 1997, the City Council has engaged in an energy-efficient lighting project to replace the existing incandescent streetlights with mercury vapour streetlights in order to reduce the electrical expenses of the municipality.

This fiscally-driven initiative delivered the unintended but welcome environmental benefits of slowing down the increase in total eCO_2 by the council and kick-starting the CCPC initiatives, which are presented in the next section.

2.2 Projects initiated under the Potchefstroom GHG reduction programme

After completion of the emissions analysis and inventory, a number of projects were initiated to reduce Potchefstroom's GHG emissions. An interdepartmental CCPC implementation committee was formed to guide the execution of the projects. These projects included the following:

- retrofitting and upgrading of streetlights;
- energy-use reduction at the airport;
- implementation of energy efficiency specifications in municipal buildings;
- recovery and utilisation of CH_4 from the sewage purification works; and
- sequestration of carbon.

2.2.1 Improvements of energy efficiencies by upgrading street lights

After the council's energy efficient lighting project in 1997, whereby modern lighting technologies were introduced to optimise cost saving measures to streetlights, further cost-effective improvements were made by introducing an efficient lighting solution plan, which included the following:

- a lighting audit to determine where cost-effective changes could be made; and
- a determination of the best technology and equipment available to optimise lighting levels including:
    - correct lighting luminance
    - minimum glare level

- low lumen depreciation factors12
- low maintenance factor
- quality assurance and ability to monitor the installation phases
- measurement and verification, which confirms and verifies the savings model.

After the audit, two projects were identified to improve the energy efficiency of street lighting in Potchefstroom. The first project entailed replacement of outdated light emitter technologies in the city's main thoroughfares with more energy efficient emitters. The second project focused on a residential area to determine whether these, more efficient technologies, are socially acceptable.

Before retrofitting[13] began, the streetlights in Potchefstroom were fitted with 200-watt incandescent light emitters. The energy used by these light emitters varied between 5 882 049 kWh and 7 651 773 kWh per year.

Due to inaccurate investigations by the Council in 1997, a number of 200-watt incandescent streetlights were retrofitted with 125-watt mercury vapour (MV) lights. Further investigations in 2002 proved that the MV lights are problematic to dispose of in an environmentally responsible manner because of the mercury

[12]The gradual loss of efficacy (lumens per watt). One lumen equals the amount of light generated by a single standard candle.

[13] New fittings must be fitted to accommodate the new light emitters.

contents of these lights. Due to the fact that no safe disposal of the MV lights was available in Potchefstroom and that the supplier, at that stage, could not ensure the correct manner of disposal of these lights, an alternative had to be investigated. 70-watt High Pressure Sodium (HPS) lights were found to give an even bigger saving than the MV lights with a better light luminance and a life span of approximately four times that of incandescent light emitters. By examining the electricity consumption of the streetlights, before and after retrofitting, the HPS light emitters proved to save approximately 50,5% more energy than the 200-watt Incandescent lights previously used (Table 6). This is a 28,5% larger saving than what was achieved with the MV lights.

Table 6: Practicality of light emitters used for possible energy and financial saving

Emitter	% Energy saving	Advantages	Disadvantages
Incandescent	Baseline (no saving)	No retrofitting necessary	High energy costs and GHG emissions
Mercury Vapour (MV)	23%	Uses 23% less energy than the incandescent light emitters.	Retrofitting is necessary; Mercury content makes it problematic to dispose of in an environmentally responsible manner.
High Pressure Sodium (HPS)	50.3%	Uses 50.3% less energy than the incandescent light emitters; Safe and easy disposal of emitters possible; Better light luminance than MV	Retrofitting is necessary; True colour of objects not totally rendered Some disadvantages referring to perception of the three-dimensional properties of objects

Thoroughfares

By July 2003 a total of 7334 of the old 200-watt incandescent streetlights had been upgraded with 125-watt MV and 70-watt HPS light emitters in the main thoroughfares in Potchefstroom at a total cost of R608 350 as part of the municipal maintenance cost. The used incandescent light emitters were removed and stored for maintenance of other streetlights that had not yet been upgraded, in order to save on future maintenance costs. This resulted in a total annual saving of 400 390 kWh, equivalent to an eCO_2 saving of 340.3315 tonne/a, which in monetary terms amounts to an average annual saving of R88 085 (Table 7 and Table 15).

Table 7: Environmental and monetary aspects of retrofitting the thoroughfares

Factor	Amount
Project cost (Rand)	R608 350
Annual kWh saving	400 390 kWh
Annual eCO_2 saving	340.3315 tonne
Annual monetary saving (Rand)	R88 085

Pilot study: residential area

The next step in the GHG reduction plan was to retrofit in a residential area. However, the city engineers were reluctant to replace the existing 200-watt incandescent or 125-watt MV light emitters with 70-watt HPS light emitters in residential areas, arguing that the yellow-coloured HPS emitters have an unacceptable colour rendering index (Cri), as the true colours of objects are not rendered. It is generally believed that people in residential areas prefer white light that enhances recognition of colour. It is also argued that the monochromatic nature of HPS lamps inhibits perception of the three-dimensional properties of objects, making it difficult to recognise for instance the height of a pavement or facial features and that the characteristics of the lights may lead to visual discomfort and inhibit productivity and/or safety (Grobler & Van der Merwe, 2002). Because such a big energy saving had been achieved by retrofitting in the thoroughfares in Potchefstroom and because of the better luminance of HPS lights, it was decided to retrofit one of the suburbs in Potchefstroom with the same lights as a pilot project to test social acceptance of this emitter in the residential areas. After retrofitting of these lights and after giving the residents six months to comment on the change, no negative complaints were received from persons residing in this area.

The Mieder Park residential area was selected for the pilot project, and a total of 110 200-watt incandescent streetlights were replaced with 70-watt HPS light emitters at a total cost of R65 700.00, excluding labour. This project was funded as part of the municipal maintenance cost. An annual saving of 21 180 kWh was achieved with this project (Cronje, 2002, pers. comm.), with an eCO_2 saving of approximately 18 tonne/a and an annual monetary saving of R4 659 (Table 8 and Table 15).

Table 8: Environmental and monetary aspects of retrofitting of Mieder Park

Factor	**Amount**
Project cost (Rand)	R65 700
Annual kWh saving	21 180 kWh
Annual eCO_2 saving	18 tonne
Annual monetary saving (Rand)	R4 659

2.2.2 Retrofitting of the airport runway and taxiway

The lighting system at the airport had become obsolete by 2000 and maintenance was becoming very expensive. The system had also been badly damaged by lightning. This resulted in the airport being labelled 'no lights available'.

Instead of the incandescent lights usually used on a runway, it was decided that a new, low-maintenance and low-energy system must be implemented as part of the GHG reduction plan. The low-energy system at the airport was implemented in two phases.

At the end of 2001, as part of the first phase of the upgrade, the airport runway was retrofitted with small compact florescent tubes. These tubes emit the same light luminance as incandescent lights while using much less energy. They comply with the South African Civil Aviation Authority (SACAA) requirements, which prescribe the amount of light that must be emitted.

During phase two, the taxiway was upgraded with a proper lighting system that complied with the SACAA license requirements. The old system was retrofitted with 11-watt blue-covered compact fluorescent tubes and was completed by June 2002.

The airport was retrofitted as part of the maintenance cost, which amounted to R172 890, of which R89 070 was for material and R83 820 was for labour. Actual energy savings in the first year were 57 244 kWh (Cronje, 2002, *pers. comm.*), with an eCO_2 saving from this project of approximately 48 657 tonne/a and an annual monetary saving of R13 739.

In addition to the savings made by retrofitting the airport lights, a wind turbine was deployed at the airport in 2005. This turbine, which costs approximately R75 000, was provided to the Potchefstroom municipality on a promotional basis by a private company in order to determine its efficiency in Potchefstroom. The turbine generates approximately 1, 5 kW at an average wind speed of 6km/hour to charge large batteries as backup energy to be used on days without wind, thus rendering an additional saving of 6 570 kWh/a and 5 585 kg of eCO_2. With the deployment of the wind turbine and with the retrofitting of the runway and taxiway, a total annual saving of 63 814kWh was achieved with these projects (Cronje, 2002, *pers. comm.*), with an eCO_2 saving of approximately 54 242 tonne/a and an annual monetary saving of R13 739 (Table 9 and Table 15).

Table 9: Environmental and monetary aspects of upgrading the airport

Factor	Amount
Project cost (Rand)	R172 890
Annual kWh saving	63 814 kWh
Annual eCO_2 saving	54.242 tonne
Annual monetary saving (Rand)	R13 739

2.2.3 *Incorporating energy efficiency specifications into the building plans of new municipal buildings*

Local municipalities can reduce GHG emissions by enhancing building energy efficiency through codes and by-laws, establishing insulation and lighting standards for new construction and retrofits of existing buildings (Betsill, 2001). It was therefore included as part of the Potchefstroom GHG reduction to improve energy efficiency in the new municipal complex that was constructed in 2002-2003.

The design specifications of the new Municipal Council Building were audited against the new South African Energy and Demand Efficiency Standard (SAEDES). SAEDES is an energy efficiency guideline for new and existing commercial buildings. Its purpose is to provide a framework for technical and performance provisions and to reduce a building's energy consumption and/or demand, thereby improving energy- and cost-effectiveness of the commercial building sector (Grobler & van der Merwe, 2002).

Following the SAEDES audit, conducted by the Electrical and Mechanical Engineering Department of the North West University (Potchefstroom Campus) and the architect of the building, modifications to design specifications were made without adding any additional costs for construction to ensure that the new building fully complied with the SAEDES requirements (Bosshoff, 2002, *pers. comm.*).

The main consideration of this project was full compliance with SAEDES. This was achieved by placing special emphasis during the design phase on the orientation and size of the building including the orientation of the windows, to ensure that the negative effects of the seasons were minimised. The mechanical and electrical parts of the building were designed in such as way as to save as much energy as possible without compromising on the ergonomic and architectural qualities of the building and without incurring any additional costs. Various measures, e.g. the construction of a cavity in the walls of the building, were implemented to insulate the building from the elements thereby ensuring minimum usage of electrical heating and cooling (Bosshoff, 2002, *pers. comm.*).

This aim was achieved and included the following:

- regarding the mechanical installation, acceptable indoor levels were met, thereby ensuring minimum fresh air of 5 l/person/second;
- economical temperature regulation;
- energy efficient fluorescent lighting to reduce energy usage while acceptable lux levels were still achieved;
- the building was also fitted with daylight switches; and
- the daylight switches were linked to occupancy.

When compared to 'traditional' buildings of the same measurement and occupancy, the new Municipal Council Building demonstrates that, as a result of the SAEDES intervention and design, a total annual saving of 16 475 kWh is achieved with an eCO_2 saving from this project of approximately 14 tonne/a and an annual monetary saving of R3 080. In contrast to the retrofitting projects, no costs were incurred in achieving these savings.

Table 10: Environmental and monetary aspects of construction of the new Municipal Council Building

Factor	Amount
Project cost (Rand)	R0
Annual kWh saving	16 475 kWh
Annual eCO_2 saving	14 tonne
Annual monetary saving (Rand)	R3 080

2.2.4 Recovery of methane from the sewage treatment facility

The fourth major CCPC project involved intervention in the sewage works in order to reduce GHG emissions. This project was partly funded by ICLEI and partly by the municipality as part of their maintenance cost.

At the old sewage treatment facility in Potchefstroom, a diesel-fired incinerator was used for incinerating the solid screenings from the mechanical rakes, and anaerobic digestion was used for the treatment of the raw sewage. At this facility, approximately 835.704 tonne of CH_4, 25.55 tonne of SO_2 and more than 781.392 tonne of CO_2 were emitted into the atmosphere every year as a result of the anaerobic digestion process (Table 11). This amounts to 18 331.176 tonne of eCO_2 per year. The diesel-fired incineration of the solid screenings was an additional source of GHG, using approximately 20 000 litres of diesel per year, resulting in further GHG emissions of approximately 543.01 tonne of eCO_2/a (Table 12). This brings the yearly eCO_2 emissions from the sewage treatment facility to 18 874.186 tonne. (Calculations were made by using the ICLEI CCP software for South Africa.)

Initially a decision to stop anaerobic digestion was taken due to the amount of GHGs emitted during anaerobic digestion and because proper digestion was aerobically possible. However, the screenings from the mechanical rakes proved to be problematic. Two options to treat the screenings were considered. One was to discard it on a landfill site, and the other was to continue with incineration. Because of the negative environmental effects of discarding the screenings on a landfill site, it was decided to go the route of incineration. To avoid the cost and negative environmental impact of fossil fuels that were used previously, methane (CH_4) recovery from anaerobic digestion was initiated. The aim of the sewage treatment facility upgrade was to capture the methane (CH_4) usually emitted into the atmosphere and to use this recovered energy source to incinerate solid screenings of the inlet at the sewage treatment works.

Three[14] of the four existing digesters were refurbished and fitted with gas collection equipment. These have enough capacity to generate the necessary biogas for incineration. The gas is collected in a 1000m^3 gasholder and then piped to the incinerator, which was refitted in order to allow for biogas or diesel[15] incineration. The gasholder holds enough gas for one day's incineration. With this in place, the amount of primary settled sludge fed to the digesters is

[14] Only three digesters were necessary to achieve the required amount of CH_4 for the daily incineration process. The fourth digester is currently not being used.

[15] In case of CH_4 failure.

controlled in such a way that little additional CH_4 is formed. The rest of the sludge is returned to the plant via an acidifying tank to be bacterially broken down in the presence of oxygen. As the incineration demand increases, as a result of population growth, more CH_4 will be generated under controlled conditions. As a result of improved control over methane generation, significantly less methane is generated when compared to previous arrangements where the methane was simply emitted into the air.

At the new facility, a total of 172.072 tonne of CH_4 (3 613.511 tonne eCO_2) and 243.784 tonne of CO_2 will be produced every year. This CH_4 will be captured and used for incineration of the solid screenings. After incineration, the combustion process will have reduced the eCO_2 content of the gas used for incineration substantially, from 3 613.511 tonne of eCO_2 to only 473.241 tonne of eCO_2 per year (Table 11).

Table 11: Old and new sewage treatment facility digestion configurations (excluding energy usage)

OLD FACILITY (Digestion)			**NEW UPGRADED FACILITY (Digestion)**					
Emissions (tonne/a)	eCO_2 of GHG Produced (tonne/a)	Total GHG emissions (tonne/a)	GHG Production (tonne/a)	eCO_2 of GHG Produced before incineration (tonne/a)	Incineration	eCO_2 of GHG Produced (tonne/a) after incineration	Total GHG emissions (tonne/a)	Total eCO_2 saving (tonne/a)
835.704 (CH_4)	17549.784	18 331.176	172.072 (CH_4)	3 613.511	Incineration	473.241	717.025	17 614.151 (96% Saving)
781.392 (CO_2)	781.392		243.784 (CO_2)	243.784	Incineration	243.784		

(Nell, 2002)

With the new process, the sludge not used in the digestion process needs to be bacterially broken down in an aerobic process. To aerate this sludge, the rotators or aerators need approximately 800 000 kWh per year. The aeration will therefore lead to a slight increase in electricity consumption and subsequent GHG emissions of approximately 680 tonne eCO_2 per year (Table 12). This indicates that, although the aerators will use more electricity and subsequently emit 680 tonne of eCO_2 per annum as a result, they will also discontinue the use of diesel, saving 543.01 tonne eCO_2 per annum. This ultimately signifies that the new facility will only emit 136.99 tonne of eCO_2 per annum more as a result of energy usage. This, however, is a small quantity when compared to the total eCO_2 saving achieved by this project. In future, options of producing and using more biogas to operate the aeration process could be investigated.

Table 12: Energy usage at the old and new plants

OLD PLANT ENERGY USAGE		NEW PLANT ENERGY USAGE		
Diesel used (l/a)	eCO_2 emissions (tonne/a)	Diesel used (l/day)	eCO_2 emissions (tonne/a)	**eCO_2 SAVING as a result of energy usage (tonne/a)**
20 000	543.01	0	0	
Electricity used (kWh/a)	eCO_2 emissions (tonne/a)	Electricity used (kWh/a)	eCO_2 emissions (tonne/a)	
0	0	800 000	680	
TOTAL FOR OLD (eCO_2)	**543.01**	**TOTAL FOR NEW (eCO_2)**	**680**	**-136.99**

If all the eCO_2 savings as well as the increased usage of electricity and the subsequent eCO_2 emissions are taken into account, a total annual saving of 17 477.161 tonne of eCO_2 and a monetary saving of R453 600 is achieved by the upgrading of the sewage treatment facility (Table 13 and Table 15). This project combines financial savings with improvements in environmental performance as well as replacing a fossil fuel with a sustainable energy source that would otherwise have had a detrimental impact on the environment.

Table 13: Comparison between the old and new plants' emissions and overall eCO_2 savings

Source of emissions	Total emissions (tonne per year)
OLD FACILITY	
Emissions (digestion process)	18 331.176
Emissions (energy[diesel] usage)	543.01
TOTAL EMISSIONS	18 874.186
NEW (UPGRADED) FACILITY	
Emissions (digestion process)	717.025 (Saving of 17 614.151 [96%])
Emissions (energy[electricity] usage)	680
TOTAL EMISSIONS	1397.025
EMISSION SAVING	**17 477.161 (92,6%)**

Table 14 below indicates the environmental and monetary aspects of upgrading the sewage purification works

Table 14: Environmental and monetary aspects of upgrading the sewage purification works

Factor	Amount
Project cost (Rand)	R2 206 000
Annual eCO_2 saving	17 477.161 tonne
Annual monetary saving (Rand)	R453 600

2.2.5 Carbon sequestration

The City of Potchefstroom has submitted project proposals to plant 15 000 trees in the previously-disadvantaged western suburbs of the city in order to mitigate against the large amount of GHGs still emitted by the city and in order to assist with urban greening of the city. A CO_2 sequestration model that calculates the amount of carbon stored in trees with an allometric equation has been developed, presented to, and approved by Environment Canada (Nel, 2006).

A total of 4 405 trees have been planted since the baseline year of 1995 in Potchefstroom. An estimated total amount of 14 208 Kg of CO_2 is sequestrated by these trees annually. This excludes the existing trees in the city of Potchefstroom that were planted prior to 1995.

The GHG reduction projects, launched in the city of Potchefstroom under the CCP campaign, demonstrate that local governments have a variety of opportunities for controlling and mitigating local GHG emissions. They also demonstrate that these GHG reduction projects have co-benefits that assist local municipalities in addressing other issues.

2.3 Total Improvements in energy efficiencies and reduction in GHGs

As indicated above, meaningful local action to address climate change will necessitate local municipalities developing new programmes or projects to achieve additional emission reductions beyond what would have occurred if no projects were launched.

Although the Potchefstroom local municipality cannot hold back global warming by itself, it is clear from the significant GHG savings achieved, that intermediate-sized African Cities, such as Potchefstroom have the potential to make a contribution to international efforts to mitigate climate change by implementing CCP programmes and achieving the subsequent milestones.

The implementation of the Cities for Climate Protection Programme resulted in the reduction of Potchefstroom's eCO_2 footprint by 17 917.9 tonne/a, or a 44.84% saving compared to the 1995 base-case scenario (Table 15 and

Figure 3). Table 12 further illustrates the approximate expenditure necessary for a local municipality in order to achieve a tonne of eCO_2 saving in the different GHG reduction projects. Table 12 corroborates that although the recovery and usage of CH_4 from the sewage works is the highest-priced project, this type of project results in the highest eCO_2 saving as well as monetary saving per year.

Table 15. The total amount of eCO^2 and monetary savings achieved by the Potchefstroom GHG reduction projects

Facility	**Project cost (Rand)**	**Project cost per tonne of eCO_2 saved in the first year (RAND)**	**eCO_2 saved per year in tonne**	**% Savings**	**Rand savings per year**
Replacement of thoroughfare streetlights	608 350	1 787.52	340.3315	1.9%	88 085
Retrofitting Mieder Park streetlights	65 700	3 650	18	0.1%	4 659
Retrofitting of airport	172 890	3 187.38	54.242	0.3%	13 739
New mayoral wing	No extra cost	No Cost	14	0.1%	3 080
Recovery of methane from sewage works	2 206 000	126.22	17 477.161	97.5%	453 600
Tree planting (accumulating each year)	162 800	11 458.33	14.208	0.1%	No monetary saving
Total	**3 215 740**		**17 917.9425**	**100%**	**R563 163**

Global warming, like most environmental issues, is a cross-cutting issue and does not fit in to the way the majority of local governments organise themselves. In addition, not all cities are prepared to invest monetary resources in reducing GHG emissions, since doing so often requires significant up-front expenses. It is, however, proved (Table 15) that improved energy efficiencies in the city can result in large financial savings. As indicated above, the yearly financial saving for the Potchefstroom local municipality amounts to R 563 163/a. Notwithstanding this monetary saving that is achieved by the retrofitting of the streetlights, a further saving is made in the sense that the maintenance cost for the HPS light emitters is approximately 40% in comparison to the incandescent light emitters previously utilised. Although carbon trading is still a relatively new concept in South Africa, should CO_2 be traded internationally at the conservative price of US$5.00/tonne (the current average price per tonne of eCO2 ranges from 4 to 10 US$ [Gilder, 2005]), the city can generate an additional income of approximately R 90 000/a.

As indicated in Table 15, the yearly monetary saving made by the Potchefstroom municipality will remunerate the initial capital investment made by the municipality within four years of commencement of the projects. Although many municipalities in South Africa currently struggle as a result of cash-flow problems, municipalities can apply for financial assistance for the establishment of these projects from organisations and agencies such as the US Environmental Protection Agency, the World Bank and ICLEI. The study has shown that the economic savings achieved by the CCPC projects may assist local governments in reducing possible future cash-flow issues.

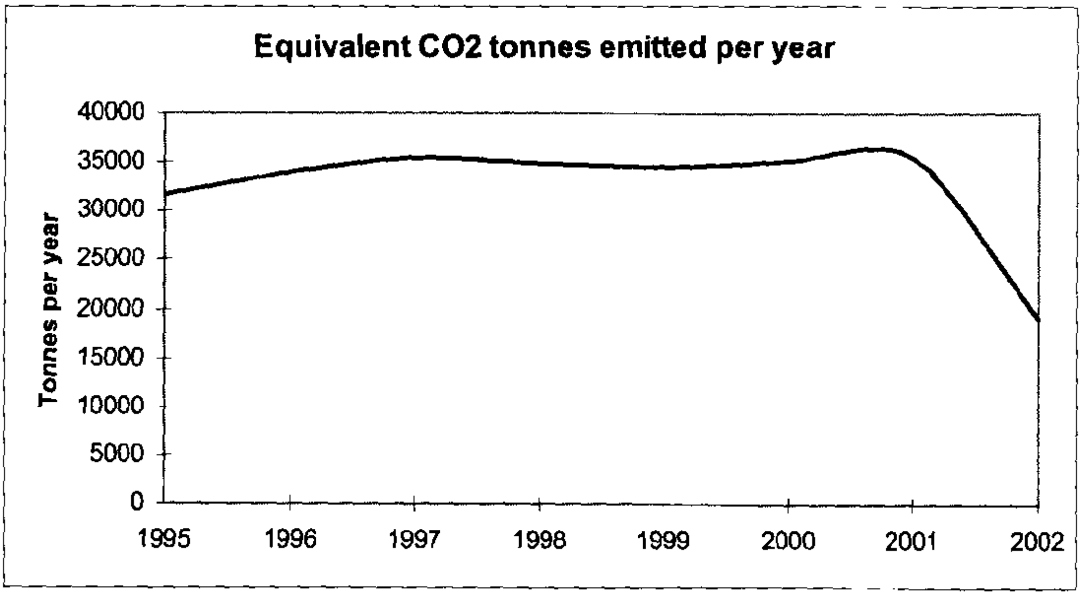

Figure 3. The emissions performance of Potchefstroom since 1995

Most city municipalities, similar to the Potchefstroom municipality, are divided into a few specialised departments with very specific mandates. Municipal officers usually focus only on their own responsibilities, often with little interface with individuals and projects in other departments. In contrast, controlling and reducing GHG emissions requires partnerships between officers working in nearly all municipal departments.

2.4 GHG reduction projects following 2002

Subsequent to the successes achieved in 2002, the Potchefstroom City Council continued with new projects to reduce its GHG emission footprint, including:

- an additional 2 095 trees have been planted since 2002;
- the construction of several bicycle lanes in the city (at a cost of R 100 000) to ensure that cyclists feel more confident and willing to ride on bicycles in the city rather than commuting with a motor car;
- the establishment of 2 bicycle parks with 70 bicycles to use without cost, which entails –
    - two bicycle parks to be established, one in the city and the other in the nearby township;
    - seventy bicycles will be made available at the bicycle parks;
    - residents from the nearby (6 km) township will be able to use these bicycles at no cost to commute to town, instead of using a taxi (Potchefstroom Local Municipality, 2005);
- LPG conversion of 56 Council-owned vehicles at a cost of R 395 000; and
- this conversion will imply an annual GHG saving of approximately 47 tonne/a.

ICLEI is providing all the funds as well as technical assistance for the above-mentioned projects.

3. Discussion

Several of the projects initiated by the local government in Potchefstroom ensured improvements in the energy efficiency of various facilities, while others ensured direct reductions in GHG emissions by means of methane recovery and the use of alternative energy options that reduce the amount of GHG emitted.

It was evident during this study that local governments have a variety of opportunities for controlling local GHG emissions and that doing so has co-benefits that help municipalities address other issues. However, global warming is generally perceived as a global issue and many local decision makers, therefore, do not construe it as something with which they should be concerned. As a result of this perception and because of other pressing socio-political and socio-economic issues and priorities, getting the mayor, councillors and other major role players committed to sustainability issues is another major obstacle in mitigating GHG emissions in cities such as Potchefstroom. The Potchefstroom experience has shown that the deciding factor to get the major role players to invest municipal capital to reduce GHG emissions, was the possibility of large economic saving obtained by the CCPC projects. The CCPC projects also had to be linked to issues already present on the local agenda.

A very important issue to address when initiating energy reduction and GHG emission reduction projects is to ensure that not only the mayor role-players, as individuals, are committed to the initiatives of the projects, but that the commitment and total buy-in of the city council as a whole is achieved, and that the council supports the process robustly and enthusiastically. The success of such projects cannot be achieved solely by the drive of one or a few persons in the city council. This was demonstrated by a lack of interest that was observed when a new mayor was elected in 2004. However, the GHG reduction policy and goals had been sufficiently entrenched to prevent the projects being terminated due to lack of political will.

4. Conclusion

Experience in the city of Potchefstroom has shown that improvements in energy efficiencies may be achieved very cost-effectively, while the return on investment is acceptable. Improvements in energy efficiencies may also be used in other intermediate-sized African cities as low risk investment opportunities with high positive outcomes, which may be offered to decision makers to embark on the journey of improved environmental performance that would otherwise have had a very low priority.

This study demonstrates that it is possible to address reduction of GHG emissions in local government, by connecting the reduction of GHG emissions to matters already present on the local agenda. It is substantiated that, although it apparently makes little economic sense for a city government to disburse capital to mitigate its GHG emissions, projects with climate-related benefits can assist local governments to achieve co-benefits such as economic savings, due to cheaper maintenance costs and cheaper running costs as well as a better quality of living for people residing in the city. Improving energy efficiency can also contribute to employment creation through the use of local contractors and can therefore also facilitate economic development. Local strategies that integrate environmental objectives can improve the competitive advantage of cities in their challenge to attract investments, commerce and high-skilled labour (Betsill, 2001).

This article demonstrates that it is economically feasible to implement GHG reduction projects in intermediate-sized South African cities and that these cities can be incorporated into global efforts to mitigate climate change.

The relatively large GHG reduction achieved in the city of Potchefstroom (17 917.94 tonne /a) demonstrates that intermediate-sized South African cities, such as Potchefstroom, can, firstly, be successfully incorporated into global efforts to mitigate climate change, and secondly, tackle social and economic issues, such as poverty, unsustainable production and consumption, and the adequate management of resources as required by Local Agenda 21.

Localising global warming to local governments is a necessary and essential move in developing a municipal response to climate change. However, it may be more difficult for some local governments to move from political will and buy-in to policy action. The experience of Potchefstroom suggests that it is most likely easier to achieve co-operation in a city of intermediate size than in a larger city, due to the fact that fewer people are involved in the process, officials have interaction between departments, and the divisions between departments are not as clearly defined with specific mandates as in larger cities. On the other hand, cities of intermediate size have an advantage over smaller towns and cities in that they have sufficient resources and the necessary infrastructure to successfully implement such a programme.

Decisively motivating municipalities to reduce their GHG emissions in order to mitigate global climate change calls for indirect strategy. The primary benefit of an indirect approach to achieve local GHG emission reductions is that it avoids many of the political debates about the science of climate change. Betsill (2001) states that it really does not matter whether global climate change science is credible, since the emphasis is now more on how reducing GHG emissions can help local governments address other more pressing local problems.

Although local governments will not stop or mitigate global warming on their own, it is clear from this study that they have the potential to make a vital contribution to international efforts to mitigate climate change. It is imperative, therefore, that they be encouraged to continue with their efforts to do so. Similar to Betsill's (2001) study, this study also suggests that the most effective way to motivate local governments to participate in the effort to mitigate GHG emissions and subsequently global warming is not by talking about 'thinking globally, acting locally'; the best strategy may be to 'think locally, and act locally'.

REFERENCES

Anstuategi, A. & Escarpa, M., 2001: Economic growth and the greenhouse gas emissions. *Economical Economics*, 40, 23-37.

Betsill, M.M., 2001: Mitigating Climate Change in US Cities: opportunities and obstacles, *Local Government*, 6 (4), 393-406.

Bilodeau, J. & Nel, J.G., 2002: Greener governance at local level, Paper delivered at the Konrad Adenhauer Stiftung African Journalist Programme, unpublished.

Borchers, M, 2003: State of Energy Report: City of Cape Town, Sustainable Energy Africa, Cape Town.

Bulkeley, H. 2000: Down to earth: Local government and Greenhouse policy in Australia, *Australian Geographer,* 31 (3).

Curnow, P. & Goldblatt, M., 2004: Climate Change: The risks and opportunities for South African Business as the world responds, *Cramer Media's Engineering News*, 24 (25) 16-17.

Darier, E. & Schule, R., 1999: Think Globally, Act Locally: Climate change and public participation in Manchester and Frankfurt, *Local Environment,* 4 (3).

El-Fadel, M. & Massoud, M., 2001: Methane emissions from wastewater management, *Environmental Pollution,* 114, 177–185.

Eskom, 2000: *Environmental Report 2000, Towards sustainability.* (http://www.eskom.co.za/environmentalreport01/index/htm) (accessed 10 April 2002)

Grobler, L.J. & Van der Merwe, C.A., 2002: SAEDES evaluation of the new council chambers of the Potchefstroom City Council, unpublished.

Gwebu, T.G., 2002: Energy sector policies in Botswana and their implications for global climate change, GeoJournal, 56, 83–92.

Hewitson, B.C., 2005: Vulnerability and Adaptation Assessment, *Regional Climate Change Scenarios*, Final Report, University of Cape Town

Ho Kim Hin, D., The Yoke Chong, R., Kwok Wai, T., Briffet, C. 1997: The greening of Singapore's national estate, *Habitat INTC*, 21 (1) 107-121.

Houghton, J., 1997: *Global Warming: the complete briefing, 2nd ed.*, Cambridge University Press, Cambridge.

Hulme, M. & Turnpenny, J., 2004: Understanding and managing climate change: the UK experience. *The Geographical Journal*, 170 (2) 105-115.

Intergovernmental Panel on Climate Change: Third Assessment Report, 2001: Cambridge University Press, Cambridge (http://www.grida.no/climate/ipcc).

International council for Local Environmental Initiatives (ICLEI) 2002: *Cities for Climate Protection* (http:www.iclei.org/co2/index.htm).

ICLEI, N.d.: The International Agency for Local Governments (http://www.iclei.org) (accessed 4 March 2002).

ICLEI. 1997: *Local Government Implementation of Climate Protection*: report to the United Nations, Toronto.

Kates, R.W., Mayfield, M.W., Torrie, Ralph, D., Witcher, B. 1998: Methods for estimating greenhouse gases from local places, *Local Government*, 3 (2)

Layman, F. 1997: *The Greenhouse Trap: what are we doing to the atmosphere and how can we slow global warming, 8th ed.*, Beacon, Boston.

Lennon, S.J., 1993: The enhanced greenhouse effect and the South African power industry. *Journal of energy in South Africa,* 4(1) 22-26.

Meadows, M.E & Hoffman, T.M., 2004: Land degradation and climate change in South Africa, *The Geographical Journal*, 170 (2) 168-177.

National Research Council, 1991: Potential for reducing emissions of Greenhouse gases, *Confronting climatic Change: Strategies for Energy Research and Development,* National Academy Press, Washington, Ch. 4, 45-67.

Nel, G., 2006: The Implementation of urban greening projects for energy efficiency and Greenhouse Gas reductions in Potchefstroom, South Africa, Unpublished M.Sc. mini-dissertation, North West University (Potchefstroom Campus), Potchefstroom, South Africa.

Nel, G., Snyman, E. & Nel, J.G., 2002: Towards sustainability at the local governmental level – implementing the Cities for Climate Protection (CCP) programme in Potchefstroom, Paper delivered at the *IAIAsa Conference on Sustainability*, unpublished.

Nel, G., 2002a: Greenhouse gas inventory and report on greenhouse gas savings achieved by the city of Potchefstroom (South Africa), Paper on the emissions inventory and project results of the city of Potchefstroom to the International Council for Local Environmental Initiative (ICLEI), unpublished.

Nel, J.G., 2002b: The city of Potchefstroom's journey towards a greener future, Paper delivered at the *World summit on Sustainable Development (WSSD) Potchefstroom Site visit*, unpublished.

Portelli, P., 2002: A Greener Approach to Lighting our Streets, Paper delivered at the *AEEMA "Cleaner Greener Smarter" Conference*, Melbourne, unpublished.

Potchefstroom Local Municipality, 2005: Directorate Health and Environment Project, Business Plan for Transport Projects to reduce Greenhouse Gas Emissions.

Spalding-Fecher, R. & Immink, H., 2005: Hot stuff: South Africa and carbon trading, Creamer Media's Engineering News, March 11-17, 16-17.

Statistics South Africa, 2001: *Census data*.

Sullivan, K.M., 1991: Coal and the greenhouse effect, *Journal of mine ventilation in South Africa,* 44 (7) 109-115.

Thando, D., 2001: Energy sector policies in Botswana and their implications for global climate change, *GeoJournal*, 56, 83-92.

Torrie Smith Associates, 1997: Cities for Climate Protection Greenhouse Gas Emissions Software – User Guide, Version 2.0., International Council for Local Environmental Initiatives (ICLEI).

United Nations Framework Convention on Climate Change, 2003: Climate Change Secretariat, Bonn.

United Nations Framework Convention on Climate Change, 1997: The Kyoto Protocol to the UNFCCC, Climate Change Secretariat, Kyoto.

Urguhart, P. & Atkinson, D. 2000: *A pathway to sustainability*, Trident, Cape Town, 99

Ward, S. & Mahomed, L., 2003: *Energising South African Cities and Towns,* Galeforce Communication, Cape Town.

Williams, C.C & Millington, A.C., 2004: The diverse and Contested meanings of sustainable development, *The Geographical Journal*, 170.(2) 99-104.

Worthington, R. & Sherman, R. 2002: *Getting to grips with global climate change governance*, Colors, Johannesburg..

PERSONAL INTERVIEWS

Bosshoff, K., 2002: Architect, Nuevo, Personal interview regarding the New Council Chambers

Cronje, W., 2002: Electrical Engineer, Potchefstroom Local Municipality, Personal interview regarding the replacement of streetlights

Gilder, A., 2005: Environmental Lawyer, Imbewu legal experts, Personal interview regarding emissions (CER's) trading.

Marais, F, J., 2002: Magazine (Store), Potchefstroom Local Municipality, Personal interview regarding the usage of Petrol and Diesel by the City Council.

Nell, B., 2002: Chemical Engineer, Potchefstroom Local Municipality, Personal interview regarding the CH_4 recovery process.

Nell, B., 2002: Chemical Engineer, Potchefstroom Local Municipality, Personal interview regarding the Diesel and CH_4 burning process.

Van den Berg, J., 2002: Electrical Engineer, Potchefstroom Local Municipality, Personal interview regarding the replacement of streetlights

Ward, S., 2005: Former Director, Sustainable Energy Africa, Personal Interview regarding the possible processes for South African Municipalities to follow in order to achieve energy efficiency.

Weyers, H., 2002: Thesauri, Potchefstroom Local Municipality, Personal interview regarding energy costs and usage

APPENDIX 1: INTENDED JOURNAL GUIDELINES FOR AUTHORS

THE SOUTH AFRICAN GEOGRAPHICAL JOURNAL

STYLESHEET FOR CONTRIBUTORS

Authors **must** adhere to the style as laid out here when preparing manuscripts for submission to the *Journal*. Failure to do so will delay refereeing and publication. Note: S.I. units must be used throughout; tables should be appended on separate sheets; a separate list of figure captions must precede the figures; and figures should be appended on separate sheets. Figures must be clear and legible for reproduction at single column width; computer graphics of high quality are only accep2 if the linework and lettering is comparable to conventional productions.

The first page of the typescript should contain the title of the paper and the name(s) and full address(es) of the author(s) in the style shown eg:

RAINFALL AND AGRICULTURE IN THE EASTERN CAPE, 1900-1994

M.E. JAMES and R.V.B. DEANE

M.E. James
Department of Environmental & Geographical Science
University of Cape Town
Rondebosch
7700 South Africa

R.V.B. Deane
Department of Geographical & Environmental Sciences
University of Natal
King George V Avenue
Durban
4001 South Africa

The second page must repeat the title of the paper, followed by an **abstract** of approximately 100-200 words in which the principal findings of the research should appear.

RAINFALL AND AGRICULTURE IN THE EASTERN CAPE, 1900-1994

Abstract

Climatological records show dramatic variability of rainfall in South Africa as a whole during the twentieth century. In theory, agricultural productivity should match these variations, a proposition that is tested with specific reference to crop yields in the eastern Cape. Strong associations do indeed exist between rainfall patterns and agricultural activity. Other changes, such as variations in farm size and farming technologies, appear to exert little effect.

The introduction (and subsequent text) must be typed in double-spacing. The introduction should not contain any subheadings. Leave a space between paragraphs. References to be cited as shown. List citations in ascending date order, and alphabetically within the same year. One or more publications by an author in the same year must be distinguished by appending letters a, b, c to the citations. Main headings should be in bold type.

Introduction

Throughout the history, human activity on the land has been governed by the availability of water. In all the available historical research, however, little attention has been given to quantitative estimates of the precise relationship between .... Furthermore, in South Africa, data are now available for the first time which allow detailed examination of the effect of changes in farming practices on crop yields.

In their discussion the historical geography of agriculture, both Smith (1977) and Andrews (1978) show a keen awareness of the climatological constraints ...

Indent and punctuate particular points as shown, and designate alphabetically. The expression *et al.* is used when the work of more than two authors of one work is being cited. Use 'n.d.' to show that a work has no publishing date. Footnoted material to be marked with a superscript.

Rainfall Variability in South Africa

The principal rainfall variations in South Africa have been studied only recently (Reed, 1994). Preliminary screening of climatological data in Southern Africa by Deane (1980, 1983b) shows that numerous sites in the eastern Cape are subject to extreme variations (Fig. 1). Data on precipitation at selected mission stations in the nineteenth century show that:

(a) rainfall was heaviest in summer;

(b) rainfall exhibited great variations within decades[1]; and

(c) yields varied in concert with rainfall, with a lag of several months (Parker *et al.*, n.d.).

These findings differ markedly from those reported in the study undertaken ten years ago during storm conditions (Brown, 1986), but approximate those made by Gill (1989).

Type subheadings in italics, aligned with the left margin of text. Avoid placing subheadings directly after a main heading. Refer to Figures and Tables as shown. Quantities less than ten should be expressed verbally, otherwise numerically.

Agriculture in the Eastern Cape

Information pertaining to crop yields at 1 117 Cape farms disclose a strong geographical variation which is best understood in terms of two major regions.

The Northern District

The two most distinctive features of yields in this part of the country are ... (Figs 2 and 3). Altogether, ten per cent of the crop yields ... Precipitation at each of the stations shows a very pronounced diurnal variation (Table 1). Early morning and early evening patterns are similar excepting at land lying higher than 1 000 m, but at all other times ...

The Southern District

There are three notable components evident in the eastern zones of the study area (Deane, 1993a). As suggested elsewhere (Francis, 1977, 1978) these accord well with observations that ...

Direct quotations should be cited using double inverted commas and must contain a page(s) reference. Direct quotations which are more than three lines in length should be inset from both margins and typed in single spacing without inverted commas. Avoid ending a paragraph with a long direct quotation.

Rainfall-Agriculture Relationships

In her landmark study, Tessig (1965, p.89) proposed that in dry areas especially, regional studies of arable and pastoral activity which failed to attend to climatic constraints were `a charade'. Others have made the same argument (Yelch, 1962; Bore, 1988), although Tedious (1977, pp. 286-287) has noted that:

> Direct links between climate and agriculture are never proven absolutely until the likely mediating affect of human agency can also be ascertained, and this is the true challenge facinginterdisciplinary research science today.

Taking these various opinions into account, and bearing in mind the well known warning given in 1902 by a Government minister, [2] who ...

Equations should be laid out as shown below:

The relationship between rainfall and production of maize may be expressed as follows:

$$P = 1,53R + 0,86T \qquad (1)$$

where P is production in tonne ha^{-1}, R is January-March rainfall in mm, and T is a measure of technology levels (Gill, 1989).

Do not introduce new material in the conclusion, and do not use point form in this section. Acknowledgements should follow immediately after the text.

Conclusion

In the eastern Cape during the twentieth century the nature of agricultural activity correlates extremely strongly with patterns of rainfall. On the one hand, ... On the other hand, ...

Taking into account the major differences pinpointed in the Cape region, it is reasonable to suppose that...

Acknowledgements

Grateful thanks are due to M.J. Mouse who drew the maps, and to the Dollar Foundation which provided financial support for the research. The conclusions reached are solely those of the authors.

Footnotes should be kept to a minimum and must be collected numerically at the end of the typescript. Use small superscript digits to number the notes, and indent the text of the notes. Notes should be used for archival references and **not** as a device for elaborating the text or making asides.

Notes

[1] Central Archives Depot, Pretoria (CAD), Department of Agriculture (DA) 468 (12/345): Memoranda concerning production of grain in the colonies, March 1976 - December 1993

[2] CAD, DA 469 (47/521): Minister of Lands to Prime Minister, 12 October 1902

[3] *Ibid.*, 9 December 1902.

The reference list

The reference list is **not** a bibliography and must contain only material which is cited in the text. **Complete information should be provided for every reference.** Organise the references alphabetically without numbering. The initials of authors and/or editors must appear behind the surname(s). Use the convention 'Anon.' to refer to unknown authors. Do not use '*et al.*' in the reference list. Date of publication must appear as in the examples. Punctuate all material exactly as shown. The only words which are capitalised in the titles of journal articles are proper nouns. The titles of journals should **not** be abbreviated. Book and periodical titles should be italicised. Volume numbers must be included for journals, but part numbers should only be used if the pagination in successive issues is not sequential. The names of book publishers and city/town of publication must be included. Monographs and dissertations/theses to be cited in the style shown. Leave a blank line between references.

References

Anon., 1943: The roaring coastal winds, *South African Panorama*, 24 (7), 2-6.

Barnes, J., Smith, M.L.B. and Frames, R. (eds), 1953: *Readings on Energy Potential in the Far East*, Hutchinson, London.

Deane, R., 1980: Trapped waves in the atmosphere, *Journal of Atmospheric Research*, 56, 1-23.

Deane, R., 1993a: Wind patterns and energy, *Science*, 123, 34-49.

Deane, R., 1993b: Assessment of wind power potential, *Journal of Applied Climatology*, 23, 1654-1659.

Francis, L., 1977: Patterns of pollen distribution in the Cape, *South African Geographical Journal*, 23, 11-19.

Francis, L., 1977: Wind and pollen dispersion: a botanical view, *Botany, 87, 94-105,*

Gill, A.E., 1977: Coastal lows from the synoptic point of view, *Quarterly Journal of the Royal Meteorological Society*, 14, 77-99.

Hunter, I.J., 1994: The Weather of the Agulhas Bank, Unpublished M.Sc. Dissertation, University of Natal, Durban.Kirby, M.J., 1976: The problem of wind power, in Jones, A.B. (ed.), *Estimating Techniques for Climatologists*, Oxford University Press, Oxford, pp. 123-129.

Parker, N.J., Ray, P., Band, T., Luk, O. and Farr, R., n.d.: *Mission Stations of the Eastern Cape*, Bantam Press, New York.

South Africa (Republic), 1976: *Annual Report of the Department of Water Affairs*, Government Printer, Pretoria.

Sample figure and table captions

These should be presented on separate sheets immediately preceding the figures.

Figure Captions

Figure 1: The spatial variation of rainfall off the east coast in the summer of 1949 (from Wetty, 1954).
Figure 2: The geography of crop yields.
Figure 3: Rainfall - crop yield relationships, 1944-1954.

Table Captions

Table 1: Farm size classification in the Cape, 1956-1978 (Source: South Africa (Republic), 1976).

APPENDIX 2: CARBON SEQUESTRATION MODEL

Calculation of Carbon sequestration

For determining the amount of CO_2 sequestrated in a tree, it is important to first calculate a few variables. The mass of the tree has to be calculated and from that the mass of the roots can be calculated. The mass of a tree includes the water content of the tree as well, and this has to be subtracted. The carbon content of the dry wood mass has to be calculated, and finally, the mortality of the tree must be taken into consideration. There are different models developed for the calculation of each of these variables. The model that was used at Potchefstroom is a combined model of some of the applicable models developed elsewhere.

The model of Arneth, *et al.*, (1998) and Lloyd, *et al.*, (1995) to determine the tree carbon (C) uptake (Net Primary Productivity excluding fine root turnover, NNP) was one of the models used. The abovementioned method is a complicated method because information on many parameters must be available.

According to studies done by Sing & Yadava (1991), above ground biomass increases with age and with increasing diameter breast height (DBH). The DBH of a tree is sufficient to determine the root biomass when the soil properties are non-restrictive.

Martin, *et al.* (1998) developed allometric equations for mature trees of 10 deciduous species. These equations included the following dependent variables: stem wood mass, stem bark mass, branch mass, total wood mass, foliage area, stem surface area, sapwood volume and total tree volume. High correlation coefficients (r2) were observed for all variables versus stem diameter, with the highest being for total tree biomass, which ranged from 0.981 to 0.999 (Martin, JG *et al.*, 1998).

Determining the amount of CO_2 sequestrated in a tree can be obtained from a statistical model. Carbon sequestration can be calculated by means of allometric relations between stem thickness at DBH and total tree mass.

For the calculation of the biomass of the trees in Potchefstroom, the total tree biomass of the newly planted trees in the city was calculated.

After the total mass of all these trees had been calculated, the dry wood mass was calculated. According to Matthews (1993), and Ragland *et al.* (1991), it is generally accepted that the dry wood mass of a typical tree is approximately 50 % of the wet wood mass.

Calculations

From Martin *et al.*, (1998) the following logarithmic equation was obtained:

Log10 Y = a + b (log10 X)

Y = variable above ground biomass in kg

a and b = values in equation

X = diameter breast height (dbh) in cm

Result: Y = 56,8kg dry above ground biomass

Plus roots 40% = Total biomass of 79,5 kg

C 50% of biomass: 79.5 kg x 50% = 39,75 kg C

For every C molecule fixated, one molecule of CO_2 is sequestrated

The molar mass of C is 12 and oxygen is 16

If 12 kg Carbon is fixated = 12 kg C + (2 x 16 kg O2 sequestrated)

12 kg = 12 + 32 kg CO_2

1 kg C = 3,67 kg CO_2

The molar relation for Carbon and CO_2 is then 1: 3,67

Average per tree: 39,75 x 3.67 = 145 kg CO_2 during 20 years sequestrated

14 000 trees = 2 030 000 kg/20 years

= 101 500 kg CO_2 per year

= ± 100 tons per year

100 Mega grams CO_2 p.a. average sequestrated over a 20 year period

To calculate the amount of CO_2 that can potentially be sequestrated it is important to remember that the mortality has to be calculated. This was done by using the mortality rates, used by ICLEI International.