THE INTEGRATION OF CLIMATE CHANGE CONSIDERATIONS INTO LOCAL AIR QUALITY MANAGEMENT PLANS IN SOUTH AFRICA

by

TIRUSHA THAMBIRAN

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ABSTRACT

In recent years there has been considerable advancement in our scientific understanding of the linkages and interactions between climate change and air quality. A warmer, evolving climate is likely to have severe consequences for air quality due to impacts on pollution sources and meteorology. The issues of poor air quality and anthropogenic induced climate change further share common sources of pollutants and thus options for control. The possibility to include these complex linkages to climate change in South Africa's air quality policy, the National Environmental Management: Air Quality Act (*Act No.39 of 2004)* (the AQA), includes the use of local air quality management plans (AQMPs). The extent to which South African cities are currently incorporating climate change concerns into existing AQMPs and the opportunities for improved integration of these two issues was investigated using the eThekwini Municipality or the city of Durban as a case study. Climate change and air quality issues are currently dealt with separately in Durban, overlooking an opportunity to derive multiple benefits from integrative policies. This case study primarily focused on understanding the role that the AQMP could play in support of creating a low carbon resilient city through its influence on greenhouse gas (GHG) emissions. Emission inventories focusing on both air pollutants and GHG emissions were developed for two of the areas for intervention prioritised in Durban's AQMP, namely the road transportation and industrial sectors. The emissions inventories were used as a basis to explore air pollution interventions that are likely to result in trade-offs or synergies (or co-benefits) for GHG mitigation. For the industrial sector it was found that the implementation of industrial energy efficiency and fuel switching measures would be favourable for co-benefits. In the case of road transport, reducing the vehicle kilometres travelled by privately owned motor vehicles and improving the efficiency of road freight transport offers the greatest potential for achieving co-benefits. The case study further illustrates that in the short-to medium-term air quality management (AQM) planning may help to promote climate change awareness and action toward climate change mitigation through improved co-ordination of industrial, energy and transport plans. The introduction of voluntary programmes, municipal by-laws and or regulatory guidance from the AQA, that support strategies with co-benefits is critical to ensure that local AQMPs can be used to promote reductions or avoidance of GHG emissions. In the long-term, climate change impacts on meteorological factors that influence air quality also need to be considered in AQMPs so that the most effective interventions can be selected to support the local government's climate change adaptation goals.

PREFACE

The work presented in this thesis was carried out in the School of Environmental Sciences, University of KwaZulu-Natal (Westville Campus), from October 2007 to December 2010, under the supervision of Professor Roseanne Diab.

This study represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others it is duly acknowledged in the text.

Tirusha Thambiran

DECLARATION 1

I ***Tirusha Thambiran*** declare that

(i) The research reported in this dissertation, except where otherwise indicated, is my original work.

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DECLARATION 2

Details of contribution to publications that form part and or include research presented in this thesis

Publication 1: Chapter 1

Thambiran, T., Diab, R.D. and Zunckel, M. (2007). Integration of climate change considerations into local air quality management plans in South Africa. *The Clean Air Journal*, 16 (2), 18-26.

Ms Thambiran was involved in the writing of the paper, whilst Prof Diab and Dr Zunckel reviewed the content.

Sections of this chapter appear in this publication.

Publication 2: Chapter 2

Thambiran T. and Diab, R.D. (2010). A review of scientific linkages and interactions between climate change and air quality, with implications for air quality management in South Africa. *South African Journal of Science*, 106(3/4), Art. #56, 8 pages. DOI: 10.4102/sajs. v106i3/4.56.

Ms Thambiran wrote the paper and Prof Diab reviewed and edited the content.

Publication 3: Chapter 3

Thambiran, T. and Diab, R.D. Air pollution and climate change co-benefit opportunities in the road transportation sector in Durban, South Africa. *Atmospheric Environment* (2011), doi: 10.1016/j.atmosenv.2011.02.059.

Ms Thambiran wrote the paper and undertook the data collection, analysis and writing of the paper. Prof Diab provided supervision during the collection and analysis of data. Prof Diab reviewed and edited the content before submission to the journal.

Publication 4: Chapter 4

Thambiran, T. and Diab, R.D. Air Quality and Climate Change Co-benefits for the Industrial Sector in Durban, South Africa. Submitted to the *Journal of Environmental Management*

Ms Thambiran wrote the paper and undertook all of the data collection, analysis and the writing of the paper. Prof Diab provided supervision during the collection and analysis of data. Prof Diab reviewed and edited the content before submission to the journal.

Publication 5: Chapter 5

Thambiran, T. and Diab, R.D. The case of integrated climate change and air quality policies. Submitted to *Environmental Science and Policy*

Ms Thambiran wrote the paper and Prof Diab reviewed and edited the content.

Publication 6: Chapter 6

Thambiran, T and R.D. Diab (2010). Air Quality and Climate Change Co-benefits in Durban. Proceedings of the Annual NACA conference, 13-15 October, 2010, Polokwane, South Africa.

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CHAPTER 1:

INTRODUCTION

1.1 Introduction

Due to the synergistic and antagonistic relationships that exist in the environmental policy arena, environmental policies cannot be treated in isolation (Hayes *et al*., 2006). The concept of integrated environmental management serves as a useful framework to enhance the ability to manage a resource that is affected by anthropogenic activities (Pahl-Wostl, 2007). Integrated environmental management allows for a broad perspective to be taken, whereby all the possible trade-offs and benefits are considered at various spatial and temporal scales (Pahl-Wostl, 2007). The atmospheric composition of the earth is greatly impacted by anthropogenic emissions that lead to a variety of environmental management concerns.

The combustion of fossil fuels (coal, oil and gas) and biomass for use as energy in homes, industries and motor vehicles, leads to a wide spectrum of air emissions that include nitrogen oxides (NO_x), volatile organic compounds (VOCs), sulphur dioxide (SO_2), methane (CH_4), carbon dioxide (CO_2), carbon monoxide (CO) and particulate matter (PM). These emissions result in a variety of impacts that threaten the status of human health and ecosystems through problems such as acidification, eutrophication, anthropogenic-induced climate change and smog. Traditionally, when it comes to addressing these problems, policies and scientific research have developed independently for each of the issues.

Thus, air quality research for example, has primarily focused on traditional air pollutants namely SO_2, PM, NO_x, ozone (O_3), and CO, whereas climate change research has focused on the science of the greenhouse gases (GHGs) namely, CO_2, nitrous oxide (N_2O), CH_4, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and O_3, all of which are responsible in some measure for the internal radiative forcing of the climate.

Furthermore, the policies to address these issues have also developed at different scales. Policy related to air pollution is generally developed at a national level, with opportunities for regional and local policies, where the ultimate goal is the protection of health and ecosystems through air quality management (AQM). Climate change policy has, however, developed at an international level, with the aim to mitigate climate change through a reduction of GHGs and to adapt to the consequent damage that could occur. The dominant international policy for climate change mitigation is the Kyoto Protocol which requires countries that have ratified it, to report on GHG emissions (non-annex 1 countries) or achieve certain reductions of GHG emissions by specified time periods (annex 1 countries).

Air pollution and climate change are two issues that are primarily driven by the same action, which is the combustion of fossil fuels. Therefore it would seem that there would be synergies to integrated management of air quality and climate change concerns. Separate policies and the conducting of research in isolation of each other have resulted in the co-benefits of an integrated policy that simultaneously considers both issues being overlooked (Alcamo *et al.*, 2002; Swart *et al.*, 2004). As such we find that there was a gap in knowledge on the scientific understanding of the links between climate change and air quality. The Intergovernmental Panel on Climate Change (IPCC) in its third assessment report in 2001 acknowledged the need to investigate the linkages between climate change and air quality and as consequence of this, in the last decade there has been an emerging priority for environmental policy to develop an improved understanding of the linkages and interactions between climate change and air quality. The recently published IPCC fourth assessment report has documented some of the linkages between climate change and air quality (Denman *et al.*, 2007). Furthermore, cities in many of the developed nations such as the United Kingdom and the United States of America (USA), which have established AQM programmes, are in the process of trying to capture the synergies between AQM and climate change mitigation.

Integration of air quality and climate change policies could ultimately occur in one of two ways. The first method of integration could be achieved by considering air quality improvements as a result of climate change mitigation measures, where the reduction of traditional air pollutants is seen as an ancillary benefit to GHG mitigation. It has been documented that such ancillary benefits of GHG mitigation are more likely to be an attractive incentive for those countries with Kyoto Protocol obligations to reduce their GHG emissions (Krupnick *et al.*, 2002). Furthermore, in developed countries where the climate change agenda dominates over the air quality agenda, integrated policies may stimulate greater consideration of air pollution with subsequently wider improvements for health and ecosystems. However, in developing countries, the ancillary benefit of climate change mitigation measures that is, reduced air pollution, is more likely to be the primary objective of air pollution related policy.

Alternatively, climate change considerations can be integrated into AQM. Research does indicate that integrating climate change considerations into AQM strategies could be advantageous in developing countries. More specifically, it is recognised that there are significant benefits associated with the integration of air quality and climate change at a local level. Research shows that cities have the potential to make a significant contribution to international efforts to curb climate change as half of the world's population lives in urban areas (Bestill, 2001). This has resulted in the old adage of 'think global and act local' to be seen as being insufficient and a new strategy to 'think locally and act locally' is instead promoted (Bestill, 2001). This highlights the need to frame climate change within a local context in order to promote local action. An integrated policy at a local level would allow for the maximisation of the synergistic relationship between the two issues and the avoidance of overlaps in policies, such that there is reduction of mitigation costs and more effective monitoring. Further, at a local level, GHG reductions can be achieved alongside policies designed to improve the liveability of communities, where reduced air pollution yields short- to medium-term benefits and climate change benefits are long-term. In addition, an integrated policy approach to these issues may result in further ancillary benefits with the potential for reducing the resource and financial burden on the government, and allow for sustainable decision-making and development. Thus, there are significant incentives for developing countries to consider the climate change impacts of their local air quality policies.

1.2 Integrating climate change considerations into air quality policy in South Africa

In South Africa, there is a high dependency on combustion of coal for electricity use, where the generation of electricity from coal is the largest emitter of GHGs in the country (SA, 2009). Furthermore, the total estimated anthropogenic GHG emissions in 2000 were 365 MTonne CO_2-eq (mainly CO_2) and contributed about 1.6 % of the total world carbon equivalent emissions (Hong *et al.*, 2002).

Electricity generation from coal is also a significant contributor to air pollution in South Africa. However, air pollutant sources also stem from the industrial sector which is the largest energy consumer in South Africa, and the transportation sector which is dominated by passenger transport, carbon intensive fuels and increased motorised vehicles for public transport. Furthermore, due to poverty and the economics of the country, indoor air pollution is a major problem in the country, as fossil fuels are burnt indoors for cooking and heating.

South Africa has a constitutional obligation to provide its citizens with an environment that is not harmful to their health or well-being and furthermore, has a global responsibility to act against climate change. The South African government acceded to the Kyoto Protocol in July 2002 and is a non-annex 1 country. South Africa has proposed taking voluntary action, contingent on amongst others the provision of financial and technological support, to reduce its carbon footprint by 34% in the next 10 years (DEA, 2010).

Air quality has received much attention in South Africa in recent years due to the promulgation of the National Environmental Management: Air Quality Act (*Act 39 of 2004*) (the AQA) in September 2005. However, by dealing with the issues of climate change and air quality in isolation at a policy level, South Africa is overlooking the co-benefits of an integrative policy. At this stage of developing the country's response to climate change and the further development of air quality legislation, South Africa is perfectly poised to capitalise on an opportunity to find the most effective way of simultaneously dealing with these issues.

Furthermore, it is important to note that even though other countries have recognised the need for integrated policies, often they have fallen short on maximising the synergies of climate change and air quality. For example, the new Canadian air quality legislation is criticized as just providing 'lip service' to integration of the issues. Even though their air quality legislation does discuss air pollutants and GHGs, the mitigation and control of the pollutants are handled separately and the synergistic relationship between the two issues is not considered (Williams and Chiotti, 2006). Thus, if South Africa is able to develop more holistic air quality legislation that incorporates climate change considerations, it will not only set an example for the rest of Africa but also for many developed countries with similar AQM structures.

As it is recognised that integrating climate change considerations into local AQM plans (AQMPs) has the potential to be beneficial in developing countries, this is the method of integration that is pursued in this study. More specifically, a mechanism that will facilitate the integration of these issues at a local level in South Africa is through the AQA, which requires that each municipality or local government must include an AQMP in its integrated development plan (IDP) as required in terms of Chapter 5 of the Municipal Systems Act (*Act 32 of 2000*), where AQM focuses on finding the most cost effective air improvement strategy.

Durban has been progressive in its approach in dealing with air quality issues, with the inception of an extensive air quality monitoring network and the development of its AQMP in

2007. Furthermore, investigations into climate change in terms of key challenges, potential impacts and responses required by the local government, have also been undertaken. Furthermore, the local government is in the process of developing an integrated assessment model for determining the mitigation and adaptation measures for various sectors of the city that will be affected by climate change (Hounsome, 2007). Durban therefore, represents an ideal case study to investigate integrating climate change considerations into local AQMPs in South Africa.

The AQMP has prioritised areas for intervention that include the industrial sector, indoor air quality and road transportation (EM, 2007). As part of the AQM action plan, the local government will have to regulate the implementation of control strategies to reduce emissions of traditional air pollutants from each of the priority areas for intervention. The intention of this study is to investigate the likely impacts of air quality driven interventions within the road transport and industrial sectors on GHG emissions. A further objective is, to suggest interventions that may allow the city to best capture the synergistic relationship between traditional air pollutants and GHGs in order to have an AQM action plan in place that reduces emissions of traditional air pollutants, whilst simultaneously reducing the city's contribution of GHG emissions.

1.2.1 Statement of purpose

The aim of the project is to integrate climate change considerations into local AQMPs in South Africa. The specific objectives are:

- To understand the scientific linkages between climate change and air quality
- To make recommendations for the inclusion of emission control measures that produce co-benefits for local air quality and GHG mitigation through a case study of the city of Durban
- To use the case study of Durban to develop recommendations for the integration of climate change considerations into local AQM plans in South Africa

The key questions to be answered in this study are:

- What are the direct and indirect effects of air quality pollutants on climate change?

- What are the direct effects of climate change on air quality?
- What are the types of measures that will produce mitigation of both air pollutants and GHG emissions in the city of Durban?
- What are the key recommendations to implement the integration of climate change considerations into Durban's AQMP?
- What are the recommendations for integrating climate change considerations into local AQMPs in South Africa?

The activities to be undertaken in this study include:

- Conduct a literature review to understand the scientific linkages between air quality and climate change issues
- Creation of emissions inventories for the road transport and industrial sectors of Durban, focusing on both air pollutant and GHG emissions from fossil fuel combustion
- Analysis of emissions data based on possible emission reduction interventions to identify those measures that will result in simultaneous benefits for air quality management and GHG mitigation
- Development of key recommendations to facilitate the inclusion of climate change considerations into local AQMPs.

1.2.2. Expected relevance of this study

Reducing air pollutants produces short-to medium-term benefits for health and ecosystems. However, the goal of integrating climate change considerations into AQMPs is to have measures in place that do not contribute to GHG emissions or ideally measures that reduce GHG emissions. This project will provide the basis for understanding the linkages that exist between air quality and climate change and provide the impetus towards long-term integrative air quality and climate change policies. As local governments in South Africa begin to develop climate change action plans, to specifically control GHG sources, these plans will also have to be analysed so as to determine the optimal control strategies that harvest the ancillary benefits of reduced air pollutants.

This project, therefore, forms an integral part of the first phase towards developing integrated air quality and climate change action plans for local governments in South Africa (Fig.1.1). The analysis of potential climate change action plans would also take place in phase 1. Phases 2 and

3 of such a plan would require commitment from various stakeholders (different spheres of government, community groups, industries and researchers) within the city to ensure effective implementation and compliance to obtain the most holistic control on atmospheric emissions (Fig.1.1).

The advantages of an integrated air quality and climate change action plan is that an optimal approach for simultaneously reducing traditional air pollutants and GHGs will be developed, which will result in the improvement in quality of life of South Africans, who will encounter the short-term benefits of reduced air pollutants and which will contribute to the long-term reduction of GHGs.

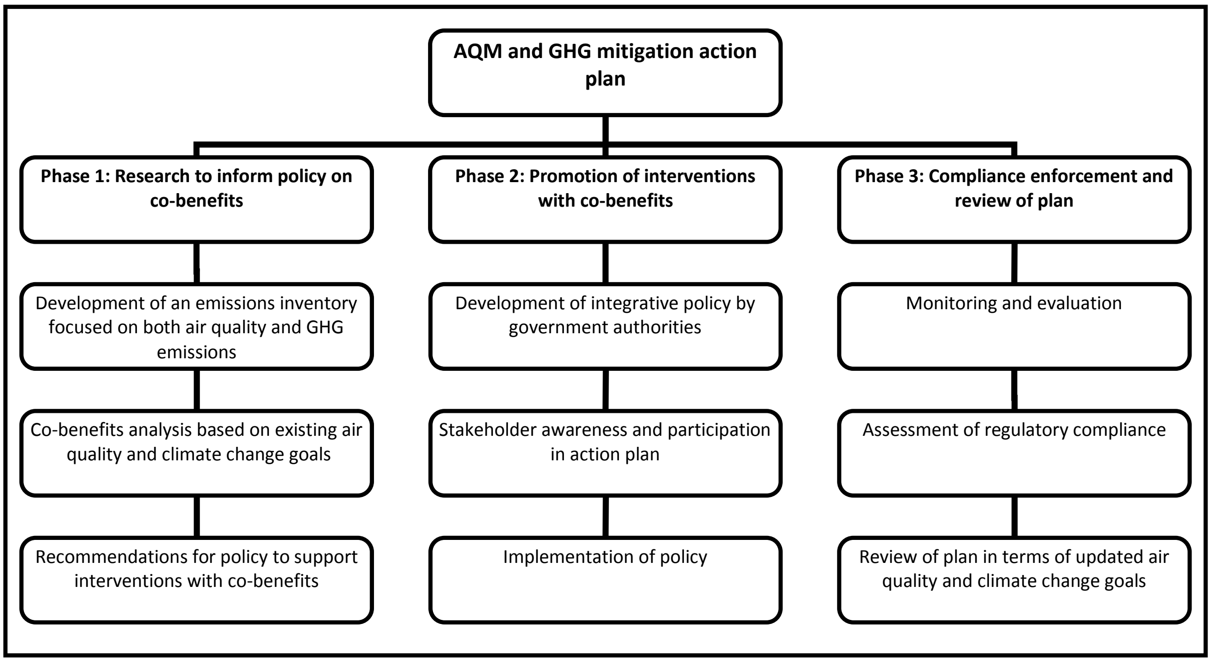

Figure 1.1: Different phases to be undertaken by local governments to develop their air quality and climate change action plans

1.3 Outline of thesis

Chapter 2 contains a detailed literature review of the linkages and interactions between climate change and air quality, covering the policy implications of this relationship within a South African context.

In **Chapter 3,** information relating to the development of an emissions inventory focusing on air pollutants and GHG emissions for the road transport sector in Durban is presented. This emissions inventory is used as a basis to explore interventions that are likely to yield co-benefits.

Measures that have been introduced in industries in Durban to effect air quality improvements are examined in terms of their impact on GHG emissions in **Chapter 4**. This chapter also contains recommendations for authorities and industries to consider for achieving co-benefits for GHG mitigation through AQM planning.

In **Chapter 5** the case study of Durban is used to discuss the extent to which cities are currently incorporating climate change concerns into existing air pollution strategies. The opportunities for improved integration of climate change considerations into local AQMPs, and actions to support the implementation thereof are also discussed.

Chapter 6 summarizes the key findings of the research and presents recommendations for further study.

Caveats:

Chapters 2 to 5 have been written in the format of research articles for journal publication. Therefore there may be some overlap in the content and references within these chapters.

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CHAPTER 2:

A REVIEW OF SCIENTIFIC LINKAGES AND INTERACTIONS BETWEEN CLIMATE CHANGE AND AIR QUALITY WITH IMPLICATIONS FOR AIR QUALITY MANAGEMENT IN SOUTH AFRICA

Abstract

In recent years there has been considerable advancement in our scientific understanding of the linkages and interactions between climate change and air quality. A warmer, evolving climate is likely to have severe consequences for air quality due to impacts on pollution sources and meteorology. Climate-induced changes to sources of tropospheric ozone precursor gases and to atmospheric circulation are likely to lead to changes in both the concentration and dispersion of near-surface ozone that could act to offset improvements in air quality. The control of air pollutants through air quality management is also likely to impact on climate change, with reductions in ozone, particulate matter and sulphur dioxide being of particular interest. The improved understanding of the relationship between air quality and climate change provides a scientific basis for policy interventions. After a review of the scientific linkages, the potential to include climate change considerations in air quality management planning processes in South Africa was examined.

Keywords: *air quality management; climate change; scientific linkages; tropospheric ozone*

2.1 Introduction

Traditionally, climate change and air pollution have been managed separately and at different spatial scales. In recent years, the understanding of the underlying science of air pollution and climate change has evolved, revealing that the relationship between these issues extends beyond a commonality of sources of emissions, to include air quality management (AQM) impacts on climate change and climate change impacts on the concentration and dispersion of air pollutants. In essence, AQM aims to bring about a reduction in air pollutants whose radiative properties may directly influence the climate, and those which impact on the lifetime and concentrations of other greenhouse gases (GHGs). Furthermore, many of the processes that play a role in the chemical composition of the atmosphere are subject to alterations due to climate change (Hedegaard *et al*., 2008) and thus may impact on air quality.

This chapter reviews the scientific linkages and interactions between climate change and air quality, focusing, in particular, on tropospheric ozone (O_3), as well as its precursor gases of methane (CH_4), non-methane volatile organic compounds (NMVOCs) and nitrogen oxides (NO_x), and particulate matter (PM). Both O_3 and PM are significant air pollutants, having consequences for human health, and are important in climate change. This chapter further highlights limitations of frameworks that propose independent air quality and climate change policies, suggesting a way forward to incorporate this relatively new and emerging understanding of the scientific linkages as a basis for policy change in a South African context.

2.2 Scientific linkages between air quality and climate change

The atmospheric emissions released during the combustion of fossil fuels include a variety of emissions that range from carbon dioxide (CO_2), which is a GHG associated with climate change, to traditional air pollutants such as sulphur dioxide (SO_2), NO_x, carbon monoxide (CO) and PM, which all affect human health and ecosystems. The complex interactions and linkages between pollutants, controlling factors and the climate are reviewed here.

2.2.1 Tropospheric O_3

O_3 is a naturally occurring gas that is best known for its important role in the stratosphere of preventing harmful ultraviolet radiation from reaching the surface of the earth. However, O_3 also occurs in the troposphere, where it is a secondary pollutant, produced as a result of photochemical reactions involving NO_x and peroxy radicals formed during the oxidation of CO, CH_4 and NMVOCs (Bunce, 1994).

Tropospheric O_3 concentrations have been found to be highly variable over time and space. Concentrations are dependent on emissions of its precursor gases and the transport of O_3-rich air masses. There is strong evidence that photochemical O_3 formation has been enhanced due to increases in emissions of precursor gases, particularly from anthropogenic sources (Marenco *et al*., 1994). Specifically, anthropogenic emissions of precursor gases have contributed to an increase of about 120% in tropospheric O_3 production since pre-industrial times (Wang and Jacob, 1999). Elevated levels of tropospheric O_3 are a concern, as O_3 affects human health and vegetation. Tropospheric O_3 is also the GHG with the third largest radiative forcing, thus contributing to the greenhouse effect and climate change (Bernard *et al*., 2001; Dentener *et al*., 2006; Denman *et al*., 2007).

Future levels of tropospheric O_3 are likely to be impacted on significantly by climate change. Studies such as those by Hogrefe *et al*. (2004) and Bell *et al*. (2007) have modelled the response of tropospheric O_3 to possible alterations in climate for the United States, predicting O_3 increases. Langner *et al*. (2005) also noted that climate change could result in increases in near-surface O_3 levels (above 40 ppb) over southern and central Europe. The impact of climate change on the chemical and transport processes that influence tropospheric O_3 is discussed below.

2.2.1.1 Climate change impacts on tropospheric O_3 photochemistry

Climate change is expected to lead to long-term seasonal changes in weather patterns, which are likely to affect the concentrations and dispersion of pollutants in the atmosphere. The factors that contribute toward regulating tropospheric O_3, such as temperature, water vapour, cloud cover and precipitation, could all be affected by climate change and are thus likely to play a role in possible future variations in O_3 (Camalier *et al*., 2007; Denman *et al*., 2007).

Temperature

As many of the reactions involved in O_3 production are temperature dependent, climate change-induced temperature changes are likely to have a significant impact on O_3 levels. High O_3 concentrations have been linked to changes in the rates of photolysis reactions. It has been documented that a strong positive association exists between near-surface O_3 production and temperatures above 32 °C (Knowlton *et al*., 2004). Studies that have modelled future O_3 concentrations have found that an increase in temperature of 2 °C leads to an increase of 2% to 4% in near-surface O_3 levels, and that an increase of 5 °C results in a 5% to 10% increase in O_3 levels (Bernard *et al*., 2001). Dawson *et al*. (2007) found that an increase in temperature led to an increase in the maximum daily eight-hour average O_3 levels.

One of the most important reactions that contribute to changes in O_3 is the temperature-dependent decomposition rate of peroxyacetylnitrate (PAN) (Dawson *et al*., 2007). PAN is formed in a similar way to O_3, due to a photochemical reaction between volatile organic compounds (VOCs) and NO_x in the atmosphere. When less PAN is produced, more radicals are available to react with nitric oxide (NO) to form nitrogen dioxide (NO_2), which is important for

O_3 production; thus the production of PAN ties up NO_x, reducing its availability for O_3 production (Baertsch-Ritter, 2004).

Changes in O_3 that are due to temperature fluctuations have been shown in both the urban and polluted rural environments, with O_3 increases linked primarily to the increased levels of NO_x due to the decrease in the formation of PAN. In addition to these impacts, temperature also plays a role in influencing the emissions from natural and anthropogenic sources of O_3 precursor gases.

Water vapour

In the troposphere, O_3 is an important oxidising agent, contributing to the formation of hydroxyl (OH) radicals (Finlayson-Pitts and Pitts Jr, 1997) through the following reactions:

$$O_3 + h\nu \rightarrow O(^1D) + O_2$$

$$O\ (^1D) + H_2O \rightarrow 2OH$$

Water vapour, as shown in the above reactions, provides a sink for O_3 due to the consumption of an excited oxygen atom. Approximately 50% of the chemical destruction of tropospheric O_3 is through the reaction of the oxygen atom with water vapour (Stevenson *et al*., 2000).

Given the significance of water vapour availability in O_3 destruction, much research has focused on the effects of changes in atmospheric water vapour on future O_3 levels (Murazaki, and Hess, 2006). It is expected that climate change will increase the amount of water vapour that is available for this reaction, thus leading to reduced tropospheric O_3 (Stevenson *et al*., 2000; Racherla and Adams, 2007). However, water vapour has competing effects on the concentration of O_3, as the OH radical that is formed plays a vital role in other reactions in the troposphere, including the production of O_3 (amount dependent on the ratio between NO_x and VOC levels), thus the subsequent reactions of the OH radical may lead to the formation of more O_3 *(*Dawson *et al.*, 2007).

Cloud cover

The presence of clouds can alter the concentration of O_3 by changing radiation transfer and vertical transport (Matthijsen *et al*., 1997). O_3 formation is reduced in the presence of clouds, and clouds deplete NO_x levels at night, making less NO_x available for O_3 production during the day (Lelieveld and Crutzen, 1991). It is also suggested that increased cloud cover, especially during the early morning hours, could act to reduce reaction rates and thus lower O_3 formation, (Bernard *et al*., 2001) whereas a decrease in cloud cover allows for an increase in photolysis rates.

Thus it is well established that changes in cloud cover can affect the photochemistry of O_3 production and loss. The impact of cloud cover on O_3 concentrations is generally regarded as minor (Dawson *et al*., 2007), with increases in cloud cover linked to small decreases in O_3. Reduced cloud cover is thought to have little effect on the concentration of $O_{3,}$ although Murazaki and Hess (2007) reported that decreases in low-level cloud water in the United States could lead to an increase in future O_3 levels. However, there are significant uncertainties with regard to the characteristics of clouds in a future climate, which raises uncertainties with regard to the modelling of cloud changes and their influence on O_3 in the future.

Precipitation

Precipitation is an important mechanism for the removal of pollutants from the atmosphere, thus also preventing further reactions and the formation of secondary pollutants. It has been shown that, when precipitation occurs, surface O_3 levels decline, and this decline is linked to the scavenging of precursor gases by precipitation and low solar radiation on precipitation days (Shan *et al*., 2009). It is expected that, in a future climate, changes to precipitation will have an impact on the rates of wet deposition of O_3 and its precursor gases.

2.2.1.2 Climate change impacts on transport processes

In addition to climate change-induced changes to photochemical reactions, there are a number of climate change-induced dynamic changes that will have an impact on the concentration of O_3.

Stratospheric–tropospheric exchange

The main source of O_3 is in the middle stratosphere. This O_3 is exchanged across the tropopause into the troposphere via a process known as stratospheric–tropospheric exchange (STE) (Guicheit and Roemer, 2000; Vaughan, 1988). The exchange of O_3 between the stratosphere and troposphere is also associated with the large-scale Brewer–Dobson circulation system (Grewe, 2009).

In general, climate change is expected to result in an increased flux of O_3 from the stratosphere to the troposphere as a result of increased STE (Collins *et al*., 2003; Sudo *et al*., 2003; Zeng and Pyle, 2003). Climate change is likely to enhance the Brewer–Dobson circulation system, which in turn is likely to affect the distribution of O_3, lifting O_3-poor air upwards in the tropics and moving O_3-rich air to higher latitudes (Zeng and Pyle, 2003). The impact of increased STE O_3 flux on the distribution of tropospheric O_3 is also likely to have hemispheric differences, due to variations in water vapour content (Sudo *et al*., 2003).

Convection

Convection is an effective mechanism for removing pollutants from the lower troposphere to the middle and upper troposphere (Collins *et al*., 2003). Convection plays an important role in O_3 production and destruction by lifting tropospheric air to regions such as the upper troposphere, where the O_3 lifetime is longer (Doherty *et al*., 2005). Convection also allows for the vertical mixing of O_3 precursors, which are transported to the middle and upper troposphere (Doherty *et al*., 2005). Furthermore, deep convection has the potential to generate lightning flashes, which result in the production of large amounts of NO in the free troposphere (Collins *et al*., 2003).

It is expected that, as the climate warms, convection will intensify in most parts of the world, with the probable exception of the tropics (Denman *et al*., 2007). Increased convection has complex implications for tropospheric O_3, as it will allow for the rapid destruction of O_3 through the transfer of O_3-rich air from the upper troposphere to the lower troposphere. However, it will also mean the injection of NO_x into the upper troposphere, where there is greater O_3 production efficiency (Denman *et al*., 2007). The convection of O_3 precursors to the upper troposphere could have potentially large consequences for O_3 production in this region of the atmosphere (Brunner *et al*., 1998) (discussed below) and possibly for near-surface O_3 concentrations as well, due to its transportation between regions.

Wind

Generally, high wind speeds are correlated with low pollutant concentrations due to enhanced advection and deposition (Dawson *et al*., 2007). This relationship is also true for O_3, (Camalier *et al*., 2007) with one study noting that a doubling of wind speed can lead to a 15% decrease in O_3 and a 41% decrease in total reactive nitrogen (NO_y) (Baertsch-Ritter, 2004). However, Holzer and Boer (2001) have shown that in a warmer climate there will be warmer winds, which in turn will lead to higher pollutant concentrations. Notwithstanding these apparent opposite trends, climate change-induced modifications to winds can be expected to influence both the dispersion and photochemical production of tropospheric O_3.

2.2.2 Tropospheric O_3 precursor gases

2.2.2.1 CH_4

Since the middle of the 19th century, levels of CH_4 have increased rapidly due to industrialisation and increased agricultural production (Lelieveld *et al*., 1998). This growth in CH_4 concentration has been attributed primarily to anthropogenic activities, with natural CH_4 sources being responsible for about a third of present CH_4 levels. The naturally occurring sources of CH_4 include the microbiological decay of organic matter under anoxic conditions in areas such as wetlands and swamps (Lelieveld *et al*., 1998). CH_4 production is influenced by temperature, with maximum production occurring at temperatures ranging from 37 °C to 45 °C (Weubbles and Hayhoe, 2002).

CH_4 is the GHG with the second largest radiative forcing. CH_4 also plays an important role in the production of background tropospheric O_3 levels, as the oxidation of CH_4 by OH in areas of sufficient NO_x leads to the formation of O_3. CH_4 is generally not considered an O_3 precursor gas, due to its long atmospheric lifetime of eight to nine years (Fiore *et al*., 2002). However, in recent years the linkages between O_3 and CH_4 have become clearer, with research pointing to a strong coupling between the changes in levels of these two pollutants. Much of the increase in tropospheric O_3 in the past is attributable to global increases in CH_4 emissions (West and Fiore, 2005). Furthermore, research has shown that a reduction in CH_4 emissions has the benefit of long-term reduction in O_3 levels and reduced radiative forcing (Dentener *et al*., 2005; West and Fiore, 2005).

The relationship between CH_4, O_3 and O_3 precursor gases is complex, as the lifetime of CH_4 is also influenced by the lifetime of other O_3 precursor gases. For example, the lifetime of CH_4 is longer when NO_x emissions are decreased and shorter when CO emissions are decreased (Wang and Jacob, 1998). It has further been documented that a 50% reduction in anthropogenic CH_4 emissions can have more influence on tropospheric O_3 burden than a 50% reduction in anthropogenic NO_x emissions (Fiore *et al*., 2002). This is due to the homogeneity of CH_4, which allows anthropogenic and natural CH_4 emissions to have equal effectiveness on O_3, whereas anthropogenic NO_x emissions are less effective than natural sources such as lightning (Fiore *et al*., 2002).

Investigations into the impact of climate change on CH_4 emissions have shown that a warming climate will act to increase the CH_4 oxidation rate co-efficient, which in most cases leads to a decrease in CH_4 levels (Stevenson *et al.*, 2000). This has implications for O_3, as reduced CH_4 means reduced background O_3 levels (Stevenson *et al*., 2000). The impact of increasing CH_4 on tropospheric O_3 levels is capable of enhancing the direct radiative forcing from CH_4 by 19±12% (Weubbles and Hayhoe, 2002).

2.2.2.2 NMVOCs

Isoprene and monoterpene represent two of the most important NMVOCs involved in tropospheric O_3 chemistry (Constable *et al*. 1999; Potter *et al*., 2001; Shallcross and Monks, 2000). These natural emissions occur in order to protect plants from abiotic and biotic stresses, and to attract pollinators (Zunckel *et al*., 2007). Isoprene in particular has been the focus of much research, as emissions in some industrial regions have been documented as being comparable to hydrocarbon emissions from biogenic sources (von Kuhlmann *et al.*, 2004). Many factors influence emissions of isoprene, including the type of vegetation, stage of leaf development, light, humidity, stress and injury. Thus, isoprene emissions are sensitive to land use and climate changes, (Lathiere *et al*., 2005) with higher temperatures generally resulting in higher emissions (Bell and Ellis, 2004; Brasseur *et al*., 2005).

Studies in the United States have shown that regions expected to have warmer summertime temperatures could experience a 50% to 60% increase in isoprene emissions (Racherla and Adams, 2007). The impact of increasing isoprene on O_3 levels was also assessed by Zeng *et al*. (2008) who showed that the impact on the global tropospheric O_3 burden was minimal, but that the greatest impact on O_3 levels occurred during summer. In areas of high NO_x, O_3 increases of 4 ppbv to 6 ppbv were noted. Meleux *et al*. (2007) found that temperature-driven change in isoprene emissions was the most important chemical factor leading to enhanced future O_3 production in Europe. Thus, the potential for climate change to have an impact on isoprene emission rates and, in turn, on O_3 production is quite high.

2.2.2.3 NO_x

NO_x ($NO + NO_2$) emissions indirectly affect the earth's radiative balance through their role in the formation of O_3, CH_4 and hydrofluorocarbons. NO_x has both natural and anthropogenic sources that include biomass burning, lightning, microbial activity in soils, motor vehicles and combustion sources that burn fossil fuels (Esen *et al.*, 2005; Palmgren *et al.*, 1996). In tropical regions, the main source of NO_x is human-induced biomass burning, (Jeagle *et al*., 2004) whereas in the northern hemisphere (NH) mid-latitudes, combustion of fossil fuels is the dominant source.

Between 85% and 97% of NO_x is emitted as NO, which is oxidised by O_3 in the atmosphere to produce NO_2, as shown in the reaction below (Esen *et al.*, 2005).

$$NO + O_3 \rightarrow NO_2 + O_2$$

Estimates of the magnitude of biogenic emissions of NO compared to anthropogenic sources remain uncertain due to the lack of data, (Delon *et al.*, 2007) although it is estimated that tropical soils account for about 70% of global soil emissions, (Jeagle *et al.*, 2004) and that soil sources contribute about 40% of NO_x emissions in Africa. Climate change impacts on the control of soil emission factors, such as soil surface temperature and moisture, (Delon *et al.*, 2007) could affect NO levels and thus modify the rate of O_3 production.

NO_x concentrations have also been noted to be rapidly increasing in the 9 km to 12 km altitude range of the atmosphere (Brunner *et al.*, 1998). Sources of this increase have not been quantified well, but include convection of pollutants from the surface, production of NO from lightning, and aircraft emissions. Lightning strikes are associated with the dissociation of molecular nitrogen, which reacts with O_3 to form NO, which then forms NO_2. Lightning, together with emissions from aircraft, are the only two direct NO_x emitters in the upper troposphere, and it is thought that lightning emissions exert a significant influence on the NO_x burden in the upper tropopause regions (Grewe *et al.*, 2001; Guenther *et al.*, 2000). It is anticipated that a warmer climate will be conducive to increased lightning, which could have a large effect on O_3 in the upper troposphere (Denman *et al.*, 2007). Murazaki and Hess (2006) predicted a significant increase in NO_x emissions over the United States from lightning, based on model simulations of climate change effects in the region.

However, it is important to note that the response of O_3 to NO_x increases depends strongly on the chemical composition of the atmosphere. For example, increased convection of VOCs to the upper troposphere may contribute to the increased efficiency of NO_x production of O_3 in the upper troposphere (Brunner *et al.*, 1998). Hence it is expected that future upper tropospheric O_3 levels will increase due to an increase in lightning-produced NO_x, as well as due to more intense transport of other precursor gases to the upper troposphere (Racherla and Adams, 2007).

In addition to the impacts of climate change on the natural sources of O_3 precursors, as described above, climate change is also likely to lead to behavioural changes that could affect the anthropogenic driving forces that contribute to NO_x and VOC emissions. According to

Bernard *et al*. (2001) climate change is likely to alter the patterns of fossil fuel use, as individual responses to warmer weather should result in changes to air conditioner and motor vehicle use, thus potentially contributing to greater pollutant emissions.

2.2.3 Particulate matter

PM is also widely acknowledged to have significant effects on air quality and human health, (Chin *et al*., 2007) as well as impacting on climate change. The term aerosols is also used to describe the fine liquid or solid particles that are suspended in the air, the sources of which are both natural and anthropogenic (Andreae and Crutzen, 1997). Two types of aerosols that are of special interest are black carbon and sulphate aerosols, due to their contribution to climate change. The main sources of black carbon are the combustion of fossil fuels and biomass burning. Black carbon is considered a component of PM_{10}, (Highwood and Kinnersley, 2006), and is known to absorb solar radiation (Bergstrom *et al*., 2007). Sulphate aerosols, which form an important component of $PM_{2.5}$, (Lui et al., 2007) occur mainly as a result of the oxidation of SO_2 (Mayehofer *et al*., 2002; Posch *et al*., 1996) and contribute to the cooling of the earth by reflecting sunlight back into space, thus preventing the sunlight from reaching the earth's surface (Andrea *et al*., 2005; Kaufman *et al*., 1991).

In addition to their radiative properties, sulphate aerosols indirectly affect climate by inducing changes in clouds. They act as cloud condensation nuclei (CCN), altering the cloud-droplet size distribution (Andreae, 2007; Hudson, 1992). Increases in aerosols yield smaller cloud droplets and thus a larger cloud albedo, often referred to as the 'cloud albedo effect', where the decreased droplet size and increased droplet number result in increased reflectivity, (Lohmann and Feichter, 2005; Mitchells and Johns, 1997) which in turn contributes to surface cooling. Aerosols that enhance the scattering and absorption of solar radiation can also affect the climate in the short-term by influencing rainfall patterns, by producing brighter clouds that suppress precipitation and thus limit the efficient removal of pollutants (Ramanathan and Feng (2009). Ramanathan and Feng (2009), noted that a rapid reduction in SO_2 emissions without corresponding reductions in black carbon and GHGs would accelerate global warming, thereby highlighting an important link to AQM processes that specifically deal with a reduction in SO_2 and PM emissions.

Indications are that a warming climate will support the accumulation of aerosols in the atmosphere. This has been demonstrated by the heat-wave weather conditions in the United Kingdom in 2003, which were favourable for the build-up of aerosols from both anthropogenic emissions and from secondary sources (Vautard *et al*., 2007). However, according to Jacob and Winner (2009), correlations of PM with meteorology are not as strong as those observed with O_3, making the assessment of the impact of climate change on aerosols more difficult to predict. It is expected that temperature increases will result in greater sulphate aerosol concentrations due to faster rates of SO_2 oxidation, whereas nitrate and semi-volatile components could decrease (Jacob and Winner, 2009). Studies that have modelled the impact of climate change on $PM_{2.5}$ have indicated $PM_{2.5}$ decreases associated with increases in precipitation, and variable $PM_{2.5}$ responses to changes in the different component species of $PM_{2.5}$ (Avise *et al*., 2009; Hogrefe *et al*., 2009; Tagaris *et al*., 2008). As the extent of the influence of climate change on these factors is not yet precisely known, these projections of $PM_{2.5}$ cannot be accepted with great certainty.

2.3 Implications of the scientific linkages and interactions for climate change and air quality policies

The improved understanding of the linkages and interactions between climate change and air quality as discussed above provides a platform for policy-makers to re-examine the traditional approaches to dealing with these issues. A brief review of current policy shortfalls in addressing the emerging scientific basis for integrative air quality and climate change policies is presented in this section.

The Kyoto Protocol was designed to achieve a reduction in GHGs as a means of preventing what the United Nations Framework Convention on Climate Change deemed dangerous anthropogenic interference in the climate system (O’Neill and Oppenheimer, 2002). Ratified by 183 countries, (UNFCC, 2009) the Kyoto Protocol prescribes emission reductions, covering a set of six GHGs, namely CO_2, CH_4, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, for the period 2008–2012 (Reilly *et al*., 1999). O_3, aerosols and the related precursor gases that influence the climate are not targeted for reduction by the Kyoto Protocol. This is due to the short lifetimes of these gases in the atmosphere, and due to the pollutants having impacts on the local and regional scale (Rypdal *et al*., 2005). The science to quantitatively assess how climate change will affect the precursor gases of O_3 and its radiative forcing is currently regarded as being inconclusive and thus further impedes its inclusion in climate change policies. By not considering the impacts of the short-lived gases, the Kyoto Protocol provides a conservative estimate of the impact of fossil fuel combustion (Smith and Haigler, 2008).

Air quality policies also reveal inadequacies in addressing climate change issues. Firstly, AQM processes generally do not consider GHG mitigation or the implications of air pollution control on climate change. This is relevant on various levels, as the AQM processes that result in a reduction in sulphate aerosols and black carbon may have consequences for climate change. Specifically, measures taken to reduce SO_2 would reduce the short-term radiative cooling of sulphate aerosols, which are thought to mask global warming effects, whereas reductions in black carbon and tropospheric O_3 would contribute toward reducing radiative warming. Furthermore, the actual methods that are imposed to reduce air quality pollutants through end-of-pipe technologies, fuel switching or structural changes may have positive or negative implications for GHG emissions (Swart *et al*., 2004).

Secondly, air quality management plans (AQMPs) are generally developed on the assumption that the climate will remain constant. Research into the potential effects of climate change on air quality has highlighted the need for policy-makers to design their AQMPs considering the influence of a changing climate (Bell *et al*., 2007; Giorgi and Meleux, 2007; Leung and Gustafson, 2005), in order to determine if the assumption of a constant climate in such plans is invalid and thus likely to work against all the proposed strategies to reduce air pollution.

2.4 Air quality policy and climate change in South Africa

In South Africa there is a high dependence on the combustion of coal for electricity, which contributes toward the country being ranked amongst the world's top 25 GHG emitters, contributing 1% of total CO_2-eq in 2004 (SBT, 2007). The combustion of fossil fuels at power plants and in the processing industries, road transportation and residential sectors further contributes to significant air pollution in the country.

Previous South African air quality legislation, in the form of the Atmospheric Pollution Prevention Act (*Act No. 45 of 1965*) (the APPA), was based on the best practicable means of preventing air pollution, where a source-based method of control was applied and no consideration was given to the cumulative effects of emissions on the ambient air. The APPA was regarded as being inadequate and outdated, (SA, 2003) as it allowed for the deterioration of ambient air quality. The APPA further did not facilitate the achievement of every South African citizen's right to an environment that is not harmful to their health and well-being, as stated in the constitution of South Africa (DEAT, 2007) and was thus also regarded as being unconstitutional. It was replaced with new air quality legislation in the form of the National Environmental Management: Air Quality Act (*Act No. 39 of 2004*) (the AQA). The AQA signalled a shift in AQM towards a receiving environment approach, with guidelines on how AQM for the country should advance, and was followed by the development of South Africa's National Framework for Air Quality Management in 2007 (DEAT, 2007), which provided the tools to give effect to the AQA by outlining procedures and standards for air quality improvements in the country.

Thus, South Africa has been making progress in seeking the most appropriate methods of improving air quality in the country. This shift to a receiving environment approach indicates a natural progression to include all atmospheric emissions, irrespective of their impacts on the environment. The AQA, together with the subsequent National Framework for Air Quality Management, highlight the importance of ensuring that AQM practices are compliant with the international agreements signed by the country, such as the Kyoto Protocol, and that they take cognisance of GHG emissions. However, presently there is no policy direction as to how this can be achieved, with the result that the actions and decision-making processes related to AQM ignore the potential climate change implications.

Since the current air quality legislation does lend itself to options for incorporating climate change concerns, it is imperative to begin to investigate options that would allow the country to capitalise on these opportunities during the early stages of policy development. There are various options for this to occur through AQMPs that are applied at different spheres of government in the country. AQMPs prescribe the processes that need to be implemented to ensure air quality improvements in the specific area. Figure 2.1 shows the six main steps that guide the development and implementation AQMPs in South Africa (DEAT, 2007; DEAT, 2008). The general tools and components of an AQMP comprise an emissions inventory, models and air quality standards, with caveats for public engagement and reporting to authorities.

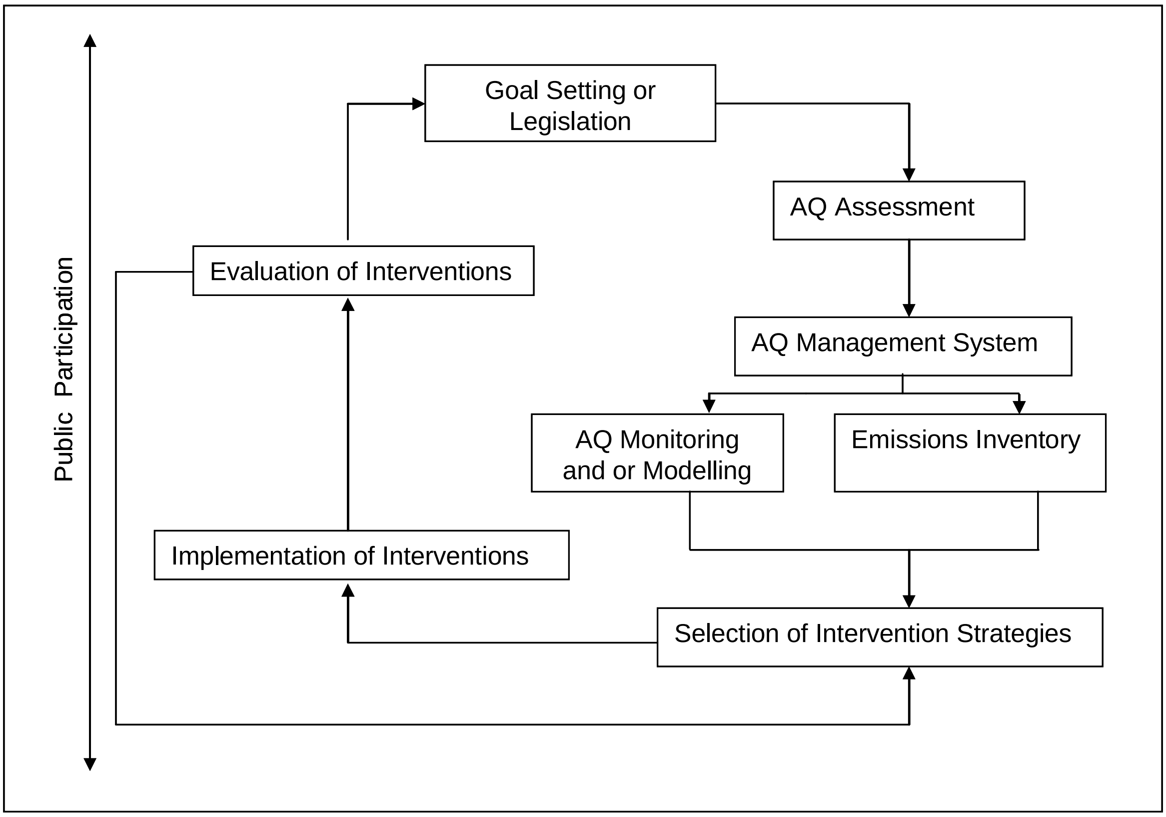

Figure 2.1: Process to be followed during the development of an AQMP (adapted from DEAT 2007; 2008)

This generic AQMP framework has room for the inclusion of climate change concerns, as the AQA states that the Minister has the discretionary power to declare a priority pollutant, indicating that GHGs such as CO_2 could be declared as priority pollutants requiring actions to reduce emissions. Thus AQMPs in South Africa could be designed to also incorporate plans to reduce CO_2 or other GHG emission. This can be achieved through legislation, as just stated, or as a voluntary measure due to increased awareness and an improved understanding of the linkages between the two issues.

The opportunities for incorporating climate change considerations into AQMPs are shown in Figure 2.2. Firstly, information on GHG emissions can be included in the baseline assessment and AQM system of AQMPs. The inclusion of GHG emissions in these components of an AQMP will enable more effective management of atmospheric emissions, allowing for the selection of intervention strategies that simultaneously reduce air pollutants and GHG emissions. Secondly, the impact of AQM processes on climate change has to be investigated to understand the climate implications of reducing tropospheric O_3, its precursor gases and PM. Furthermore, the long-term design of AQMPs needs to include an impact assessment of future climate change on air quality (such as tropospheric O_3) in order to determine if additional or more stringent controls will have to be implemented to meet air quality targets.

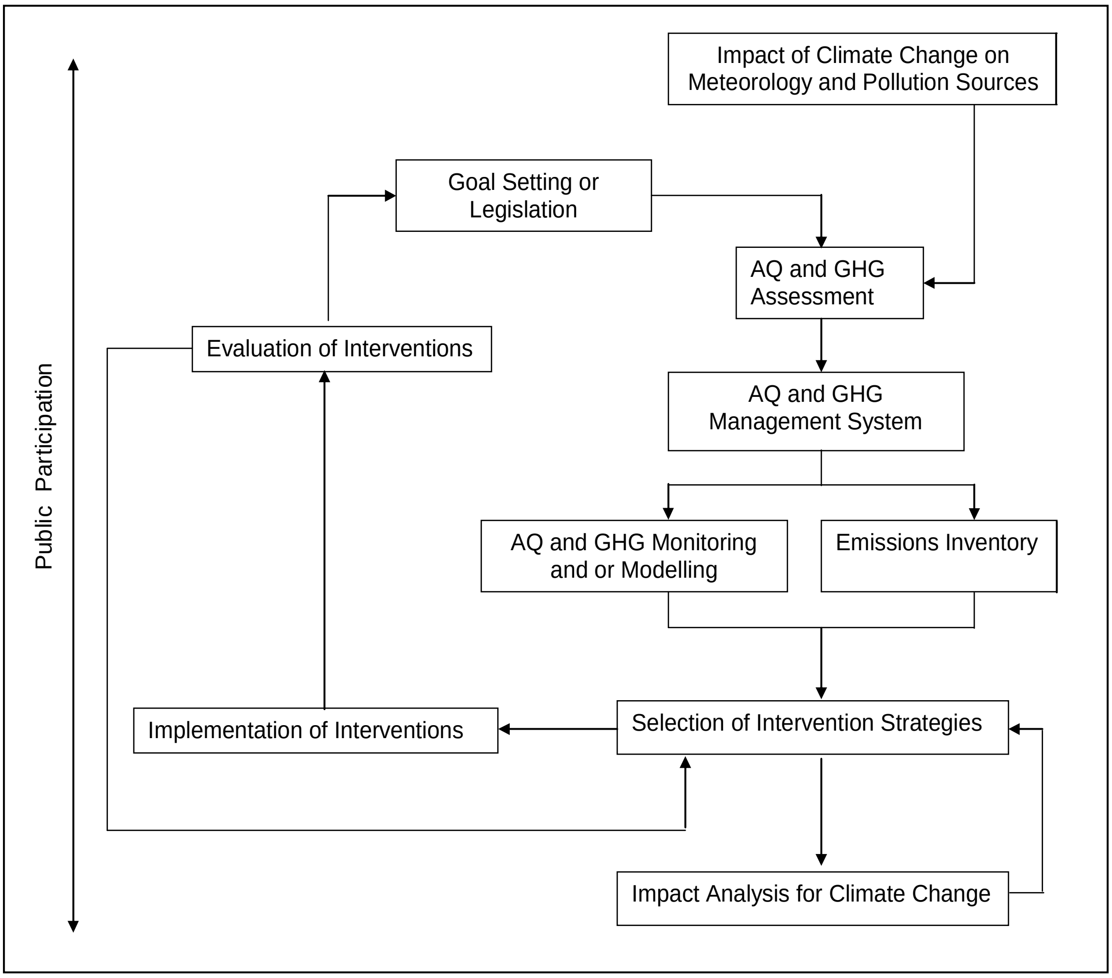

Figure 2.2: Integrative process to be followed during the development of an AQMP

2.5 Conclusion

Climate change and air quality represent two major environmental challenges that have many scientific linkages and interactions. Specifically, tropospheric O_3, its precursor gases and PM represent AQM priorities that demonstrate close links to climate change.

From an air quality perspective, predictions of the long-term reduction in emissions for AQM are thought to be misleading, as such estimates are based on the assumption that the climate will remain constant. This presents a problem, as most of the processes that play a role in the chemical composition of the atmosphere are subject to alterations due to climate change. Many studies have tried to assess, through model analysis, the impact of climate change on future air quality, as a means to quantify the possible impacts on human health and thus guide policy responses. O_3 has been used as the pollutant of choice in such studies by virtue of the fact that it is more sensitive to changes in temperature and weather than other pollutants, and that it allows for the best predictions to be made over long timescales. Model results of projections of future surface O_3 concentrations indicate that these levels are likely to increase. The effects of climate change on other air pollutants, such as PM, are less understood than those on O_3.

From a climate change perspective, AQM processes that bring about a reduction in tropospheric O_3 and black carbon would contribute to a reduction in climate warming, although a reduction in SO_2 could offset the short-term cooling that occurs. The complex linkages and interactions indicate that separate air quality and climate change policies are insufficient, signalling a need to move toward more holistic, integrative air quality and climate change policies. In South Africa, opportunities exist for AQM procedures to capture climate change linkages through AQMPs.

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CHAPTER 3:

AIR POLLUTION AND CLIMATE CHANGE CO-BENEFIT OPPORTUNITIES IN THE ROAD TRANSPORTATION SECTOR IN DURBAN, SOUTH AFRICA

Abstract

The contribution of the road transportation sector to emissions of air pollutants and greenhouse gases is a growing concern in developing countries. Emission control measures implemented within this sector can have varying counteracting influences. In the city of Durban, South Africa, the growing dependence on privately-owned motor vehicles and increasing usage of roads for freight transport have all resulted in significant air pollution and greenhouse gas emissions. In this study, an emissions inventory was developed for the road transport sector and was used as a basis to explore intervention opportunities that are likely to reduce simultaneously, air pollution and greenhouse gas emissions in this sector. It was found that reducing the vehicle kilometres travelled by privately-owned motor vehicles and improving the efficiency of road freight transport offered the greatest potential for achieving co-benefits.

Keywords: *road transport; air quality; greenhouse gas emissions; South Africa*

3.1. Introduction

Globally, the transportation sector is estimated to contribute about 25% of carbon dioxide (CO_2) emissions, with the road transport sector responsible for 80% (WRI, 2007). Emissions to the atmosphere are determined by the quantity of fossil fuel consumed by the vehicle, vehicle technology, fuel quality and transportation land-use planning (Soylu, 2007). Research shows that measures implemented to control emissions from this sector, may result in unintended secondary impacts. Emissions of both greenhouse gases (GHGs) and traditional air pollutants make the road transport sector a suitable choice for investigating opportunities for implementing a co-benefits approach to tackling air quality management (AQM) and climate change mitigation.

The co-benefits approach is based on the principle of co-control of atmospheric emissions to yield simultaneous benefits for climate change and air quality. The co-benefits approach in road transport has been applied in cities such as Bogota (Woodcock *et al*., 2007), London (Beevers and Carslaw, 2005) and Mexico City (McKinley *et al*., 2005) and has successfully demonstrated the multiple environmental and social benefits of atmospheric emission reductions in the road transportation sector.

The co-benefits approach to AQM and climate change mitigation in this sector is of particular relevance to developing countries as they often face numerous air quality challenges and are also considered the fastest-growing source of GHG emissions (Gan, 2003). Many countries in Africa are typically characterised by poor road transport infrastructure and aging motor vehicle fleets that are poorly maintained, both of which contribute to increased emissions (Zachariadis *et al*., 2001).

Surprisingly, there has been little emphasis on co-benefits research for the road transportation sector in Africa. South Africa, which represents the largest economy in Africa, has in recent years made significant strides toward investigating and understanding the opportunities for GHG mitigation in the country (SBT, 2007), paving the way for prospects to develop innovative GHG emission reduction strategies. However, there has been no consideration of GHG emissions within a co-benefits framework, with opportunities for co-control of emissions and the simultaneous reduction of air pollution and GHGs.

The purpose of this chapter is to determine the contribution of the road transportation sector to GHG and air pollutant emissions in Durban and to investigate opportunities for co-control of emissions. Section 3.2 of this chapter provides a description of legislation and policies related to road transportation emissions in South Africa. Section 3.3 details the development of the road transportation emissions inventory for Durban. Options to simultaneously reduce air pollution and GHG emissions from this sector are discussed in Section 3.4, together with estimates of the emission reductions that potentially can be achieved. Section 3.5, provides some key recommendations for implementing a more integrative approach to managing atmospheric emissions within this sector.

3.2. Overview of legislation and policies addressing road transportation emissions in South Africa

The transport sector is dominated by the use of liquid fuels that are heavily dependent on the import of crude oil (Vanderschuren *et al*., 2008). This sector contributes ~9% to South Africa's total GHG emissions (SA, 2009). The road transport sector, which is responsible for 88% of the national transport sector energy demand (Haw and Hughes, 2007) is therefore the largest contributor to GHG emissions in the sector. From an air pollution perspective, Wicking-Baird *et al*. (1997) and Scorgie *et al*. (2004) have identified road transport in major South African cities such as Cape Town, Johannesburg and Durban as contributing significantly to carbon monoxide (CO), nitrogen oxides (NO_x) and particulate matter (PM) emissions.

In response, the South African government has implemented measures to reduce harmful motor vehicle emissions. Certain constituents of fuels such as lead and sulphur are known to have adverse health effects and to be incompatible with vehicle pollution control technologies. The phasing out of lead-based petrol began in 1996, with lead being completely phased out by 2006. The phasing out of lead-based fuels has had two important outcomes in South Africa; the first is linked to its direct reduced impact on human health, and the second is that it has allowed the introduction of catalytic converters which control vehicle emissions (Stead and Molden, 2009).

In terms of Section 23 of the National Environmental Management: Air Quality Act (*Act No.39 of 2004*) (the AQA), vehicles can be declared as controlled emitters if they are likely to impact on the environment and health, and vehicle emission standards will be developed. An implementation strategy for the control of exhaust emissions from road-going vehicles was gazetted in 2003 (SA, 2003), thus allowing for motor vehicles to be considered as controlled emitters under the AQA. The overall approach used in this strategy was based on the example of European standards for vehicle exhaust emissions and fuel specifications as shown in Table 3.1, which also describes the present and future vehicle emissions standards as currently implemented and proposed for motor vehicles in South Africa.

The first phase of this strategy required that both diesel and petrol be manufactured with an upper sulphur limit of 500 ppm, with an option for a low sulphur grade diesel containing 50 ppm sulphur. The reduction in the sulphur content of petroleum products enabled the use of vehicles with advanced vehicle technologies, such that in January 2006 all newly manufactured vehicles sold in South Africa were required to conform to Euro 2 and Euro II emission standards. The overall aim of the strategy is to ensure that all newly manufactured vehicles comply with Euro 4 and Euro IV standards by January 2012 (SA, 2003).

Table 3.1: Fuel specifications for South Africa and Europe (Adapted from SA, 2003)

	Unit	2006	2008	2010+	Euro 2	Euro 4
Petrol						
Reid vapour pressure	kPa	65		undetermined	70	
Benzene	% by volume	3	3	undetermined	5	
Maximum Sulphur	ppm	500	500	50	0.05 % by mass	50
Diesel						
Sulphur	ppm	500	500 and 50	50		

3.3. Case study of Durban

Durban has a population of over 3.5 million and a passenger car ownership that is above the national norms, at 189 per 1000 population. A recent household travel survey highlighted the dependence of passenger travel on motor vehicles. The presence of the Durban port, manufacturing industries and the Durban International Airport further contribute to high traffic volumes of slow-moving heavy vehicles on the roads.

An air quality management plan (AQMP) has been developed for Durban (EM, 2007*a*). Though primarily focused on interventions within the industrial sector, the AQMP does recognise that road transport is a significant source of air pollution. Continuous air quality monitoring undertaken by the municipality as part of its AQMP suggests that there is a growing contribution of vehicular traffic to air pollution in certain parts of the municipality, including areas along major freeways and the Durban city centre (EHD, 2007; 2008), with frequent exceedances of PM and NO_x ambient air quality standards reported. Additionally, road transport is considered to contribute to over 25 % of Durban's total GHG emissions (EM, 2006).

Durban has taken some steps to reduce congestion that include the introduction of a bus lane on a major freeway, the widening of heavily congested roads, and the construction of flyovers. Other efforts have directly targeted improvements to public transport with indirect opportunities for reducing atmospheric emissions. These include the nationally run taxi-recapitalisation programme and the 'Durban people mover', an initiative targeted at transporting tourists around the city.

Durban is representative of major national trends in the road transport sector and as such can be used as a case study to investigate options for achieving co-benefits within a South African context. The following section details the development of an emissions inventory.

3.3.1 Methodology

3.3.1.1 Emission factors and the COPERT model

Wong and Dutkiewicz (1998) and Stone (2000) provide emission factors for tailpipe exhaust emissions applicable to South African motorised vehicles. These emission factors were calculated for diesel (light and heavy vehicles) and petrol (passenger and light commercial vehicles for non-catalytic and catalytic) motor vehicles for coastal and interior, elevated conditions in South Africa. However, neither Wong and Dutkiewicz (1998) nor Stone (2000) provide specific emission factors for buses and passenger diesel vehicles, and furthermore, the emission factors do not include nitrous oxide (N_2O), and PM for petrol vehicles. It is also noted that these emission factors are not expressed as a function of vehicle speed.

It is generally accepted that the motor vehicle situation in South Africa resembles that of Europe rather than the United States (Wong, 1999), allowing for the use of European transport emission models. It has been shown that the emission factors developed for South Africa by Wong and Dutkiewicz (1998) and Stone (2000) are in general agreement with the emission factors that are used in the EEA Computer Program to Calculate Emissions from Road Transport (COPERT) model (DoT, 2002). More recently, Forbes and Labuschagne (2009) have found that under dense traffic conditions around Johannesburg, South Africa, COPERT values for Euro 2 emissions were only slightly higher than measured data from motor vehicles and that Euro 3 COPERT emission factors were about three times lower. The South African motor vehicle fleet is generally considered to be old, as more than 50% of motorised vehicles are over ten years old

(Stead and Molden, 2009), hence a large proportion of current motorised vehicles were purchased prior to legislative controls on emissions and therefore for the time period of this study are not expected to meet Euro 2 or Euro 3 standards. Due to the limitations of existing South African emission factors and the average age of motor vehicles in the country, the COPERT emission factors and the COPERT model were deemed suitable for the purposes of this investigation.

Detailed descriptions of the COPERT model are provided by Gkatzoflias *et al*. (2007). The COPERT IV model allows for a variety of estimates of motor vehicle emissions that include CO_2, N_2O, CO, methane (CH_4), sulphur dioxide (SO_2) and NO_x. Model inputs include vehicle counts, vehicle fuel type, fuel consumption, vehicle fleet composition or technology, vehicle mileage, and typical average speed. Details of the data inputs and assumptions made to compile activity data for the model are described below.

3.3.1.2 Activity data inputs

Vehicle speed

Information on speed was taken from various sources including case studies of major roads and from permanent traffic monitoring stations operated by the National Road Agency. This was supplemented by published data from Bester and Geldenhuys (2007) and Stone and Bennet (2001), who characterise average speed by vehicle type on major roads in South Africa, including those in Durban.

Fuel specifications, temperature and Reid vapour pressure

Fuel specifications used were obtained from the South African National Standards for unleaded petrol SANS 1958 (SANS, 2006*a*) and for diesel fuel from SANS 342 (SANS, 2006*b*). Temperature data were obtained from the South African Weather Services and Reid vapour pressure data were obtained from the strategy to control the vehicle exhaust emissions (SA, 2003).

Vehicle classification according to the COPERT categories

The National Association of Automobile Manufacturers of South Africa (NAAMSA) and Response Group Trendline supplied information about the vehicle parc for Durban. The data included the population of motor vehicles, classified by their maximum total weight, and fuel type, and applied to passenger vehicles, light duty vehicles, heavy duty vehicles and buses. There were no data on motorcycles, however, since motor cycles comprise less than 2% of the current motor vehicle parc, (Coetzee, 2008) their exclusion is justified. The vehicle parc data further did not include the numbers of vehicles of automobile manufacturers that are not members of NAAMSA, which are estimated to contribute 0.6% of the motor vehicle fleet in Durban.

The COPERT model requires that vehicles be classified according to engine capacity, weight and emission control technology, i.e. within the designated COPERT vehicle categories. It is known that for the period 1990 to 2002, only 7.3% of the total vehicle population in South Africa was equipped with catalytic converters, and that for the period 2004 to 2006, the corresponding figure for all new motor vehicles was 50% (DEA, 2008). This information together with the introduction dates for emission regulations for new motor vehicles, trends in vehicle sales data (NAAMSA and Response Group Trendline) and literature sources (Liswoski *et al*., 1996; Coetzee, 2008) were used to estimate the average age of vehicles in the parc, and further classify Durban's motor vehicle fleet into the different vehicle emission control categories specified in the COPERT model as shown in Table 3.2 below.

Table 3.2: Percentage distribution of vehicles estimated according to European emission standards estimated for 2008

European Category	**Petrol passenger vehicles**	**Diesel passenger vehicles**	**Light-duty vehicles**	**Buses**	**Heavy-duty vehicles**
ECE15-00/01	85				
Open Loop	7				
Conventional		40	84	82	83
Euro 1	4	44	6	13	13.3
Euro 2	4	16	10	5	3.7

Fuel balance and mileage

Fuel sales data for 2008 in the seven licensing districts within the municipality were obtained from the Department of Minerals and Energy. As the municipality is central to many road-freight corridors and is a tourist destination it can be assumed that significant amounts of fuel purchased elsewhere are used in the municipality and that fuel purchased within the municipality is being transported beyond its borders. An assumption was therefore made that fuel exports and imports in the municipality balance.

The fuel sales data have two purposes within this study. Firstly, they are used within the model to estimate emissions of CO_2, SO_2 and lead which are directly related to the amount of fuel that is used. The model assumes that all of the carbon and sulphur present in the fuel is fully oxidised into CO_2 and SO_2 respectively. Secondly, when using an assumption of fuel balance, actual fuel sales can be used within the COPERT algorithm to estimate annual mileages. Annual fuel consumption, fuel consumption factors and the age of motor vehicles are required to do so. As there were no official statistical data available for mileages in Durban, estimates of annual mileages were derived using this algorithm and were further disaggregated based on vehicle mileage degradation profiles developed for South African motor vehicles. The model further requires the percentage driving share of motor vehicles on different road types (urban, rural and freeway). This fraction was estimated using the total length of the local road network, the total length of freeway and the total length of the freeway and main roads.

Information regarding annual mileages of motor vehicles in South Africa and in the province of KwaZulu-Natal were sourced from the literature and questionnaires requesting mileage data were sent to industries and logistics companies within the municipality. This information was used for comparison with estimated mileages from this study. It was found that estimates of passenger motor vehicles and light duty motor vehicles were within +5 to 10 %, whilst heavy-duty vehicles estimates in this study ranged between –15 to +30% of annual mileages reported.

3.3.2 Road transport emissions inventory for 2008

The data described in section 3.3.1.2 were used as inputs into the COPERT IV model to develop a baseline inventory for 2008 of atmospheric emissions focusing on the major air pollutants (NO_x, CO, PM) and GHGs (CO_2, CH_4, N_2O). The emissions calculated are shown in Table 3. These results provide an indication of the major contributors within the motor vehicle fleet to air pollution and GHGs. Of particular interest is the role of passenger motor vehicles and heavy-duty vehicles. Passenger vehicles contribute significantly to CO emissions and CO_2 and $NO_{x,}$ whereas the heavy trucks are of a concern for CO_2, NO_x and PM.

Table 3.3: Baseline emissions calculated (tonnes per annum)

Vehicle Type	**Greenhouse Gases**			**Air Quality Pollutants**			
	CO_2	CH_4	N_2O	PM_{10}	NO_x	CO	SO_2
Passenger cars	2 140 251	1 363	115	260	25 940	180 563	670
Light vehicles	1 252 630	542	52	610	12 884	31 452	417
Heavy-duty vehicles	2 467 597	140	68	1 518	31 163	9 990	779
Buses	174 457	21	3	108	2 478	617	55
Total	6 034 935	2 066	238	2 496	72 465	222 662	1921

3.3.2.1 Comparison of 2008 emission inventory compiled for this study with other emission inventories

The determination of emissions is based on a number of assumptions which may induce a bias in the estimation of air quality and climate change pollutants. These include a conservative approach to classifying all vehicles purchased prior to 1990 as being ECE 15.01 and the estimation of annual mileage based on fuel consumption data which was assumed to be constrained by fuel consumption in the municipality.

In order to determine if the baseline inventory that was developed is suitable for further investigations, it was compared with other road transport emissions inventories undertaken for the Durban as shown in Table 3.4.

In terms of air pollution there are similarities between the different inventories. The relatively higher emission estimates for PM_{10} and NO_x found in this study can be attributed to an increase in vehicle activity and changes to the vehicle fleet over time. It is estimated that over the period of 2002-2008 the number of motor vehicles in the municipality increased by about 10%, with the number of new diesel vehicles being almost three times that of new petrol vehicles.

Table 3.4: Comparison of 2008 emission inventory compiled for this study with other emission inventories (emissions in tonnes per annum)

Pollutant	**GHG Inventory for 2002 (EM, 2003)**	**Scorgie *et al*. (2004)**	**KwaZulu-Natal Emission Inventory (KZN-DAEA, 2007)**	**State of Energy Report (EM, 2005)**	**GHG Inventory for 2005/2006 (EM, 2007*b*)**	**This Study**
PM_{10}		2 286				2 496
NO_X		62 456	61 163			72 465
CO		161 791	351 521			222 662
CH_4		915				2066
CO_2	3 308 435	4 657 456		4 489 988	5 5527 709	6 034 935
N_2O		167				238

The CO estimates of the KZN-DAEA (2007) inventory are significantly higher than other studies and can be explained as they used emission factors that were developed in 1995, during the brown haze study in Cape Town, thus sampling older vehicles, whereas Scorgie *et al*. (2004) made use of the emission factors, developed by Wong and Dutkiewicz (1998) and Stone (2000) which as described earlier are similar to the COPERT emission factors used in this study.

For climate change pollutants, similar emission factors were used in all studies. Fuel sales in the years of these studies explain the differences in estimated CO_2 emissions, as fuel sales in the municipality for 2008 increased by about 30 % compared to 2003.

The inventory developed in this study appears to be representative of the air pollution and GHG emissions in Durban and is therefore regarded as suitable to use as a basis for understanding the opportunities for co-benefits that may exist based on the present characteristics of the motor fleet and fuel consumption.

3.4. Options for reducing road transport emissions

Numerous technological and policy-based strategies have been shown to be effective in simultaneously reducing air pollution and GHG emissions from this sector. Interventions that decrease the emissions per kilometre travelled by effecting changes to vehicle technologies, fuel types and distances travelled have been shown to be successful. Opportunities to reduce emissions from this sector in Durban are explored in this section.

3.4.1 Passenger motor vehicle fleet

3.4.1.1 Petrol motor vehicles

Currently, petrol-driven motor vehicles dominate the passenger fleet in Durban, with diesel vehicles comprising only ~5% of the total. The split between the number of petrol and diesel vehicles plays a key role in determining the CO_2 emissions intensity and air pollution contribution of the passenger motor fleet, due to differences in fuel combustion characteristics and vehicle technologies.

The petroleum used by motor vehicles is made up of a mixture of aromatic hydrocarbons and paraffins, which combust at very high temperatures in the air. The incomplete combustion of the petroleum in the engine of the vehicle results in exhaust emissions of CO, volatile organic compounds (VOCs) (ozone precursor gases), and PM. The installation of catalytic converters on petrol-driven vehicles allows for the combustion of the pollutants at lower temperatures

(Heck and Farrauto, 2001) and is effective in reducing the amount of photochemically reactive hydrocarbons by 95%, with the ability to reduce the emissions of CO to below 1%.

Due to the age of the petrol-driven passenger vehicles in the municipality, the majority of petrol-driven vehicles are not fitted with pollution control technologies and are therefore a source of high air pollutant emissions as shown in Table 3.3 above. Renewal of the oldest passenger motor vehicles in the parc with newer motor vehicles of advanced vehicle technologies is one option to reduce air pollution.

The inputs into the COPERT model as described in section 3.3.1.2 were changed to reflect a 20% replacement of petrol-driven passenger vehicles that have Pre-Euro standards by petrol-driven vehicles that are Euro 2 and Euro 3 compliant (20% was chosen as a convenient figure). Based on motor vehicle degradation profiles for South Africa, we find that older passenger vehicles are generally driven less, thus the fleet renewal is expected to result in an increase in vehicle kilometres travelled (VKT) and in fuel consumption. CO_2 emissions therefore increase, whereas emissions of the ozone precursor gases (NO_x, CO) and PM which have impacts for human health and for climate change are reduced due to improved vehicle pollution technologies (Table 3.5).

3.4.1.2 Diesel motor vehicles

Diesel-fuelled vehicles generally have better fuel economy than petrol vehicles, and have been shown to emit less CO_2 per kilometre (Mazzi and Dowlatabadi, 2007). The effect of replacing 20% of the oldest petrol-driven motor vehicles with new diesel motor vehicles is shown in Table 3.5. Decreases in ozone precursor gases and CO_2 are noted, however, PM emissions increase as is expected due to the way that diesel fuel is combusted in diesel vehicles, which produces more carbonaceous emissions.

PM emissions from diesel vehicles can be reduced by diesel particulate filters (DPFs), which are made up of filter materials that are placed in the exhaust to collect any PM which is then combusted by oxidizing agents in the exhaust gas. DPFs can have efficiencies of up to and greater than 90% (Coffey, 2004) and when retrofitted on a diesel engine can reduce the effective carbon footprint by at least 20% (Johnson, 2008). These devices have been widely applied to large vehicles such as buses and construction equipment, whereas their use in passenger vehicles is still limited (Ntziachristos *et al*., 2005). Measures aimed at increasing the share of diesel motor vehicles within the passenger fleet could therefore have conflicting environmental implications.

3.4.1.3 Fuel switching

As fossil fuels contribute toward significant emissions there is a shift in research and policy to promote more renewable forms of energy such as biodiesel. Biodiesel is manufactured from vegetable oils or animal fats that have undergone a process of transesterfication that is used to improve the fuel properties, thus making it a viable alternative to diesel (Atadashi *et al*., 2010). It is generally acknowledged that when the entire life-cycle of the biodiesel is considered, it is likely to result in lower CO_2 emissions (Gaffney and Marley, 2008). The introduction of biodiesel in South Africa has been slow and due to the lower number of diesel vehicles in the passenger fleet, switching to biodiesel (Table 3.5) may not make a significant contribution to emission reductions.

3.4.1.4 Reducing vehicle kilometres travelled

Changes to vehicle technologies alone cannot bring about the emission reductions that are required in the short-to medium-term, highlighting the need for behavioural change, specifically, targeting the VKT by passenger motor vehicles. Interventions that keep the number and type of motor vehicles constant but reduce the VKT and thus reduce fuel consumption, allow for the simultaneous reduction of air pollutants and GHGs (Table 3.5). Specifically, it results in emission reductions of 15-21% across the pollutants. As CO_2 emissions are more closely related to fuel consumption, higher reductions occur compared to NO_x and CO which also rely on changes to vehicle technologies as shown earlier.

Currently, walking, cycling and public transport are not popular modes of travel due to poor road infrastructure and concerns over road safety (Bester and Geldenhys, 2007). Improvements to the public transport fleet and policy aimed at encouraging a shift away from motorised private transport are therefore needed. A range of measures based on the principles of road transport management need to be considered, and implemented according to their feasibility and a cost-benefit analysis.

Table 3.5: Passenger motor vehicle emissions (tonnes per annum)

Scenario	Greenhouse Gases			Air Quality Pollutants			
	CO_2	CH_4	N_2O	NO_x	CO	PM_{10}	SO_2
Baseline	2 140 251	1363	115	25 940	180 563	260	670
Fleet renewal with 20% new petrol vehicles	2 160 482	1128	105	21 414	148 145	256	697
Fleet renewal with 20% new diesel vehicles	2 129 071	1134	104	22 139	144 561	391	692
20% use of biodiesel	2 118 288	1345	115	25 681	178 725	260	707
20% reduction in VKT	1 755 571	1076	92	20 545	142 980	208	571

3.4.2 Heavy-duty vehicles

Transport and logistics related activities contributed for 16% of the Gross Domestic Product (GDP) in 2007 (EM, 2009). The Durban to Gauteng corridor, via Johannesburg represents the busiest road freight transport route, representing over 66 % of road freight transport to or from the municipality. The retail and light industrial sectors located within the municipality account for over 70% of the freight trips that are made (ETA, 2005), with an estimated 27.5 million tons of road freight moved along the Durban to Gauteng corridor annually (KZN Transport, 2009).

The contribution of road freight transport to emissions can be attributed to the fact that South Africa permits some of the largest vehicle combinations in the world for general freight haulage, with vehicle carrying capacities and dimensions that make road transport more competitive than rail (Lane, 2009). Road freight transport thus has numerous advantages over rail transport, which include accessibility, competitive pricing and the ability to cover as much as 18 000 km per month compared to average locomotive which travels 7 500 km per month (Lane, 2009). Furthermore, the rail route between Durban and Johannesburg is about 20% longer than the road corridor (Morton *et al*., 2006). The tonnage carried by road freight is almost twice that of rail, irrespective of the direction of the freight, with the rail link between these cities being utilitised at less than 35% of its capacity (ETA, 2005).

The Durban port handles more than 60% of all containers arriving at ports in the country (Smit, 2009). The movement of freight from the harbour through to the city represents the most heavily trafficked freight routes. In recent years, engineering techniques such as the widening of roads and the development of truck staging areas have been used to solve problems of congestion on these routes. In the long-term it has been suggested that greater use of the rail system, operated on renewable energy, could be a viable option to reduce the numerous negative impacts associated with road freight transport (SA-ASPO, 2008).

However, in the short- to medium-term, effort needs to be expended in reducing inefficiencies in the current road freight transport system through a movement toward road freight traffic management (Hull *et al*., 2008). Specifically, measures targeted at efficiency improvements, operational improvements, behavioural change programmes and speed control need to be explored. As improved logistics and efficient vehicle loading are suggested to be the most viable solutions to tackle emissions from this sector (Chapman, 2007), the use of freight internet based systems to match up spare vehicle capacity and freight needs and reducing the occurrence of empty running costs by finding return loads has to be a priority.

Interventions that reduce the VKT by heavy-duty trucks and fuel consumption can contribute to significant reductions in air pollution and GHG emissions (Table 3.6). Emissions of pollutants are reduced by 20-24 %. The higher reduction in CO_2 in this scenario compared to that of reducing VKT in the passenger vehicle fleet can be attributed to heavy-vehicles being operated primarily on diesel compared to the passenger fleet which is dominated by petrol-driven vehicles.

Table 3.6: Heavy-vehicle emissions (tonnes per annum)

	Greenhouse Gases			Air Quality Pollutants			
	CO_2	CH_4	N_2O	NO_x	CO	PM_{10}	SO_2
Heavy-duty vehicles	2 467 597	140	68	31 163	9 990	1 518	779
20 % reduction in annual VKT in normal fleet	1 881 797	112	54	24 930	7 992	1 214	590

3.5. Discussion and concluding remarks

This chapter provides an indication to policy-makers of the opportunities for co-control of emissions within the road transportation sector and should be considered when designing and implementing new road transport and air quality policies. It should however be noted that there are some uncertainties associated with these emissions estimates and that the purpose of this study is not to provide definitive reductions based on the recommended interventions, but rather to provide an indication of the reductions that are possible and how the various components that contribute to the emissions are related and can be manipulated to decrease emissions. It has to be acknowledged that the emission reductions estimated in this study may differ under real-world driving conditions. Furthermore, emission reductions may not necessarily equate to similar reductions in ambient concentrations of pollutants.

Emissions from road transport were shown to be most sensitive to distances travelled and vehicle technologies. Interventions that promote improved efficiency in road freight transport and reduced use of private passenger motor vehicles are likely to yield the most significant emission reductions. Furthermore, as the South African government plans to implement cleaner fuels regulations, the benefits of this policy can only be realised if measures are put in place to reduce the number of old, polluting motor vehicles. Therefore the motor vehicle parc, especially the passenger motor vehicle fleet needs to be rejuvenated in order to realise the effects of cleaner fuels. A combination of fleet renewal and reducing VKT needs to be explored.

Using a co-benefits approach when developing policy to reduce emissions from this sector, will allow for more effective emission reduction strategies to be developed. By taking cognisance of

GHG implications, the implementation of air quality interventions that may make future GHG emission targets more difficult and costly to attain is avoided.

If the city of Durban is to aggressively tackle GHG emissions from road transport, the uncertainty around data mentioned in this study needs to be rectified. Specifically, the development of emission factors, availability of mileage data and improved characterisation of the motor vehicle fleet is needed. Even with a complete data base of mileage of motor vehicles registered in the municipality, there is considerable uncertainty with regard to inter-municipal travel that needs to be investigated. Motor vehicles used in the municipality that are registered or fuelled out of the municipality and vice versa need to be investigated to allow for the representation of the activity of inter-municipal travelling vehicles, especially that of heavy-duty vehicles.

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CHAPTER 4:

AIR QUALITY AND CLIMATE CHANGE CO-BENEFITS FOR THE INDUSTRIAL SECTOR IN DURBAN, SOUTH AFRICA

Abstract

Industries in the city of Durban, South Africa are a major source of air pollutant emissions and hence are targeted in air quality management plans (AQMPs) aimed at improvements to ambient air quality. Industries in Durban are also large users of fossil fuel energy, a significant source of greenhouse gas (GHG) emissions. An energy strategy has been developed for the city, prioritising energy efficiency at industries as a key action. In this chapter, measures that have been introduced in industries in Durban to effect air quality improvements are examined in terms of their impact on GHG emissions. Co-benefits for air quality and GHG mitigation were realised when petroleum refineries switched from using heavy fuel oil to refinery gas and methane rich gas. At other industries, co-benefits stemmed from measures focused on reducing fossil fuel energy consumption and included the reduced consumption of grid-supplied electricity and the improved efficiency of combustion systems. Certain pollution control technologies and changes at petroleum refineries resulted in a reduction in plant efficiency levels and hence greater energy consumption. Air quality and energy policies in the city are being executed independently, without consideration of the trade-offs or synergies of the interventions being implemented. Recommendations are made for authorities and industries to consider co-benefits for GHG mitigation in their air quality management planning and where these are not possible to consider offsetting the increased GHG emissions through improved alignment with energy strategies.

Keywords: *industrial sector; air quality management; energy consumption; climate change; co-benefits; Durban*

4.1 Introduction

In many developing countries, industries are typically major sources of air pollutants (Fenger, 2009) and are therefore the focus of air quality management (AQM) strategies. Research shows that industrial interventions to improve ambient air quality have the potential to simultaneously contribute toward greenhouse gas (GHG) mitigation. Opportunities for co-benefits have been demonstrated by various types of industries (Aunan *et al*., 2004; Worrell, and Galitsky, 2005).

In the the city of Durban, South Africa, industries are significant contributors to air pollution and are considered to have the largest energy demand. The development of AQM strategies that prioritise interventions with co-benefits for GHG mitigation could contribute towards South Africa's targets in respect of GHG emissions reductions.

In this chapter, measures that have been introduced in industries in Durban to effect air quality improvements are examined in terms of their impact on GHG emissions. In addition, industrial energy improvements are considered in terms of their impacts on air pollutant emissions. Section 4.2 provides a background to South African policy legislation pertaining to atmospheric emissions from the industrial sector. In section 4.3, the case study of the industrial sector in Durban is presented, highlighting the implications of separate air quality and energy-saving interventions. In Section 4.4 the experiences from AQM and energy strategies are used to highlight recommendations for how future air quality targets should be approached. The role that industries can play in selecting intervention measures with co-benefits for climate change mitigation is presented in Section 4.5, followed by concluding remarks in Section 4.6.

4.2. Air quality and climate change policies in South Africa

In the last decade there has been a change in the legislation governing air pollution in South Africa from the old Atmospheric Pollution Prevention Act (*Act No. 45 of 1965*) (the APPA) to the dramatically revised National Environmental Management: Air Quality Act (*Act No.39 of 2004*) (the AQA). The phasing in of the AQA through the development of the National Framework for Air Quality Management (NFAQM) in 2007 (DEAT, 2007) has allowed for the development of new ambient air quality and emission standards that are strongly focused on regulating emissions from industries. Since March 2010, when the AQA came into full effect, industries are required to manage their emissions to the atmosphere through this legislation.

Table 4.1 provides a brief comparison between the requirements of the AQA and the APPA as they relate to industries. The AQA specifies that the best practicable environmental option that could prevent, control, abate or mitigate pollution and protect society and the ambient air quality from harm must be implemented (DEAT, 2004). Activities that result in atmospheric emissions which have or may have a significant detrimental effect on the environment are designated as listed activities. Listed activities include for example, petroleum refining, metallurgical and mineral processing, and chemical industries (DEAT, 2007), and require an atmospheric emissions license (AEL) to operate.

Table 4.1: A comparison of the APPA and the AQA as they relate to industries

	Classification of industrial activities	**Assessment criteria for issuing of permits**	**Regulation of emissions**
The APPA	Scheduled processes	Issue of Registration Certificates • Best practicable means (BPM) needs to be taken to limit emissions • BPM should consider the prevailing extent of technical knowledge of availabe control options and the costs of abatement	No national emission standards No ambient air quality standards
The AQA	Listed activities	Issue of Atmospheric Emission Licenses • Consideration of the pollution that will likely result and the possible effects on the environment • Best practicable environmental option is taken to prevent, control, abate or mitigate pollution • Determination of whether or not the applicant is a fit and proper person, competent to manage the listed activity	Minimum emission standards for priority pollutants Atmospheric impact reports may be requested if a person conducting a listed activity fails to comply with or is suspected to contravene conditions of the AEL or the AQA Pollution prevention plans are required for activities that involve emissions of priority pollutants National ambient air quality standards

AELs are used as a means to regulate and ensure compliance with national minimum emission standards for air pollution. Minimum emission standards are included for pollutants such as nitrogen oxides (NO_x), sulphur dioxide (SO_2) and particulate matter (PM). Such standards vary according to the type of operation and whether or not it is a new or existing source of emissions. Table 4.2 provides an example of emission standards for new solid fuel combustion installations. Existing plants are expected to reach the new plant limits within 10 years of the emissions standards coming into effect (SA, 2010).

Table 4.2: Example of emission standards for solid fuel combustion installations under the AQA (SA, 2010)

Pollutant	**Plant status**	**Emission standards (mg/m^3)**
PM	Existing	100
	New	50
SO_2	Existing	3500
	New	500
NO_x	Existing	1100
	New	750

Under the AQA, AELs require reporting on GHGs as well as the traditional air pollutants, thus requiring an AEL applicant to develop the capacity and expend resources to adequately report on GHG emissions.

In terms of climate change concerns, South Africa acceded to the Kyoto Protocol in 2002 and subsequently developed a national climate change response strategy in 2004 (DEAT, 2004). In 2006, a process that aimed to assess the potential for the mitigation of GHGs in the country began. This involved the development of a national GHG emissions inventory for the year 2000 (SA, 2009) and the subsequent long-term mitigation scenarios (LTMS). The LTMS highlighted industrial energy efficiency as key to GHG mitigation (SBT, 2007).

There are no national government policies currently in place to mitigate GHG emissions. Due to the nature of energy usage in the country, existing policies that aim to improve energy efficiency and promote renewable energy are being used to influence GHG emissions. However, due to the availability of inexpensive low-grade coal and electricity tariffs that are amongst the lowest in the world (Winkler and Marquard, 2009), national energy policy, which has set renewable energy targets, has failed to deliver significant adoption of solar and wind resources (Edkins *et al*., 2010). A Renewable Energy Feed-in Tarriff (REFIT) programme has been initiated to develop rewewable energy options, and other policies promoting solar water heating through the use of subsidies are also currently being rolled out (Edkins *et al*., 2010).

4.3. Case study of the industrial sector in Durban

The metropolitan area of Durban is the third largest urban area in South Africa. Industries contribute to over 22% of the city's Gross Domestic Product (GDP) (EM, 2009*a*). The industries include two petroleum refineries, a paper and pulp manufacturer, a large number of chemical industries and the largest motor vehicle manufacturer in southern Africa. The large concentration of process industries, particularly in the south of the city, has resulted in poor air quality that has given rise to many community complaints (Diab and Motha, 2007; Scott, 2003).

Not surprisingly, the industrial sector has been identified as a priority area for intervention under the AQA and has had a long history of intervention even under the old APPA. Specifically, in 2000, the South Durban Multipoint Plan (SDMPP) was implemented to investigate and resolve the air pollution problems in the area. It provided a framework for the key role players in the area, that is, the major polluting industries, government and the community to address air pollution issues.

In 2007, the city's first Air Quality Management Plan (AQMP) was developed and gave formal expression, with the backing of legislation, to the management of ambient air quality. The record of interventions to improve air quality even before the promulgation of the AQA provides a useful platform from which to examine observed changes to ambient air quality and to consider the changes, if any, to GHG emissions.

The starting point for the consideration of the impacts of the industrial sector in Durban on air pollutant emissions, specifically SO_2 and NO_x, and GHG emissions (carbon dioxide (CO_2)) is the compilation of an emissions inventory.

4.3.1 Emissions inventory for the industrial sector in Durban

The inventory is based on energy consumption data. Many of the industries located in Durban are energy intensive, with energy-related costs responsible for between 10 to 50% of monthly operating expenses. Industrial energy supply has been dominated by fossil fuels as they have been easily available and relatively inexpensive. This has resulted in steam boilers and furnaces in industries being mostly dependent on fossil fuel combustion for the production of steam or generation of electricity. Renewable sources of energy such as biomass are used to a much smaller extent.

Data on energy consumption by industries for the year 2008 were obtained from major industries, city records and suppliers of coal and electricity to industries. Estimates of SO_2 and NO_x emissions from each energy source were derived from fuel consumption data and local and United States Environmental Protection Agency (US-EPA) air pollution emission factors (US-EPA, 1995). The IPCC (2006) guidelines were used for estimating CO_2 emissions (Table 4.3). It must be noted that industries also produce significant air pollution and GHG emissions through manufacturing, other on-site processes and fugitive emissions. However, most industries do not have reliable estimates of direct GHG emissions, hence emission sources other than energy consumption have been excluded from this inventory.

Table 4.3: Baseline air pollutant and GHG emissions for the industrial sector in Durban (tonnes per annum) for the year 2008

Energy type	**CO_2**	**SO_2**	**NO_x**
Coal	1 810 427	10 919	5409
Heavy fuel oil	33 918	777	65
Light fuel oil	30 906	395	75
Refinery gas	1 501 218	124	1052
Paraffin	102 985	0.3	0.44
Liquid petroleum gas (LPG)	116 742	1.5	105
Methane rich gas (MRG)	249 289	8	708
Electricity	2 713 746	18 883	11 913
Total emissions	6 559 231	31 108	19 327

From this emissions inventory, it is evident that coal, refinery gas and electricity are the major contributors to GHG emissions in the industrial sector. Combustion of coal is further a significant contributor to local SO_2 and NO_x. Refinery gas and methane rich gas (MRG) also contribute significantly to NO_x emissions.

4.3.2 Air pollution interventions

Air pollution control measures are typically implemented, either through a change in the industrial process, switch in fuel or the installation of emission control equipment (Boubel *et al*., 1994). The application of these options generally varies according to the process and costs involved in respect of the atmospheric emission reductions that are required. The impacts of these measures for climate change are traditionally not considered in the decision to implement a control measure.

In Durban, the phasing out of dirty fuels and the use of improved pollution control technologies were two of the main measures used to reduce air pollutant emissions, resulting in a reduction of over 45 % in SO_2 emissions in the last decade (EM, 2007). A reduction in SO_2 emissions was the major imperative of the SDMPP and no consideration was given to possible changes to GHG emissions. For the first time the full implication of these measures for climate change, specifically GHG emissions, is explored below.

4.3.2.1 Change in fuel type at petroleum refineries

Petroleum refining industries in the South Durban Industrial Basin (SDIB) switched from using predominantly heavy fuel oil (HFO) in heaters and boilers to using refinery gas and MRG and were thus able to reduce their respective SO_2 emissions from fuel combustion sources from over 40 tonnes a day to less than 2 tonnes a day (Engen, 2009; SAPREF, 2009). Environmental performance reviews for the major industries in the SDIB, as well as municipal environmental reports, together with information from Table 4.3 were used to assess the simultaneous impact of these fuel changes on SO_2 and CO_2 emissions.

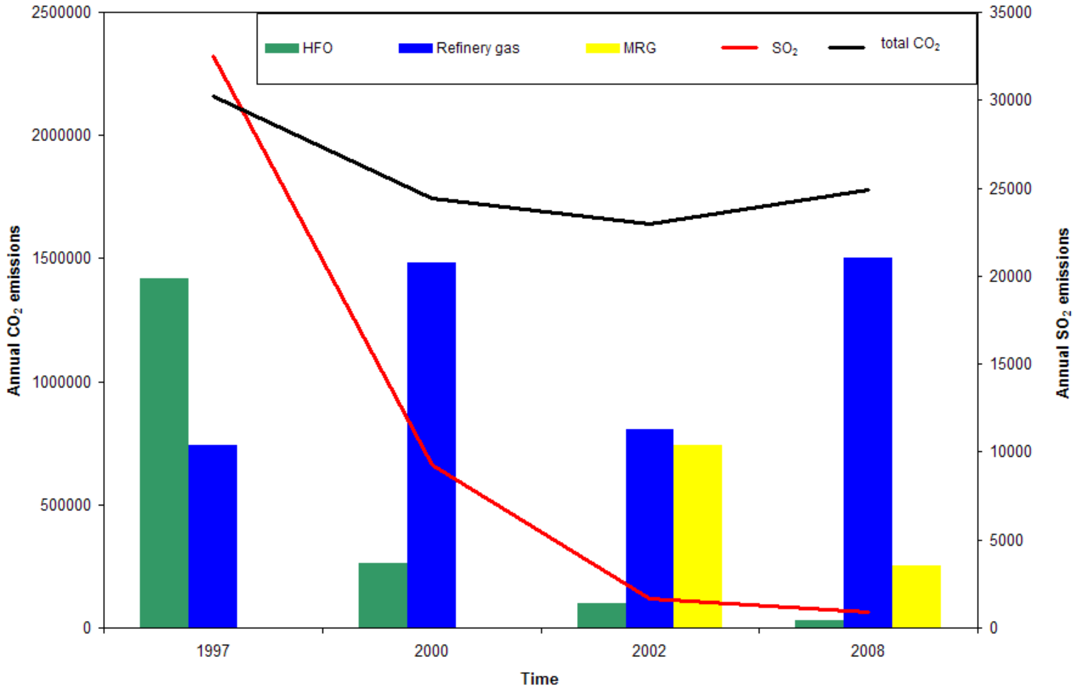

Figure 4.1: Changes in CO_2 (solid black line) and SO_2 emissions (solid red line) (in tonnes per annum) due to a change in fuels used at petroleum refineries within the SDIB

Figure 4.1 clearly depicts the decrease in SO_2 emissions over the period 1997 to 2008, from over 32 000 tonnes per annum to less than 1000 tonnes per annum, which enabled annual SO_2 ambient air quality targets to be met. CO_2 emissions are depicted separately for each of the fuel types (HFO, refinery gas and MRG), as well as cumulative totals. It is noted that there has been an overall decrease in GHG emissions over the 1997 to 2008 period, with an increase in emissions noted in 2008. The increase in emissions can be attributed primarily to changes at the petroleum refineries that occurred due to the implementation of the government-legislated improvements in fuel quality, that is, phase 1 of Clean Fuels project in South Africa. This programme required petroleum refineries to phase out the use of lead as an additive in petrol and to reduce the sulphur content of fuels produced. Structural changes and the installation of new equipment such as distillation towers and isomerisation units, were some of the measures undertaken to meet these requirements.

4.3.2.2 Change in sulphur content of coal and the installation of emission control devices at other industries

Further emission control measures introduced resulted in industries in south Durban switching from using high sulphur coal to coal with lower sulphur content. In some cases this had the effect of reducing SO_2 emissions by up to 13 %. However, these changes in quality of coal used still resulted in significant emissions of SO_2, requiring further air pollution control action to be taken. Typically, such action resulted in the installation of end-of-pipe technologies.

Air pollution reducing technologies play a fundamental role in air quality policies, reducing the volume of emissions that is generated from the processes on site, with no modifications required to the industrial process or the fuels used. The installation of wash pit and circulating fluidized bed (CFB) scrubbers are examples of this. The use of such scrubbers contributed up to a 50% decrease in related SO_2 emissions from coal combustion (Airey, 2009; Dale, 2008; Dale *et al*., 2009). The combination of switching to lower sulphur coal and using pollution control devices has contributed to a cumulative SO_2 reduction of up to 70% from certain industrial sources.

However, it must be noted that such air pollution technologies also often result in a reduction in efficiency levels of the industry, increasing fuel use by 1 to 3% and thus can have trade-offs for GHGs, if the fuel source is carbon intensive. No specific measures are documented by industries in the SDIB for off-setting the increase in energy consumption due to the installation of these pollution control devices.

4.3.3 Impact of energy consumption on air pollutant and GHG emissions

As most industrial processes typically operate with energy intensities that are at least 50% greater than the theoretical minimum that can be achieved (Worrel *et al*., 2008), energy efficient improvements can be implemented to improve operational efficiency and hence reduce costs and environmental impacts. Energy efficiency at industries has a vital role to play in developing effective pollution control policies, with GHG emission reductions of 10 to 30% possible (Saidur *et al*., 2008).

In Durban, authorities and industries have approached addressing issues related to energy consumption independently of air quality policy. Specifically, an energy strategy has been developed for the city, prioritising energy efficiency at industries as a key action. From an industry perspective, there have been various measures implemented to reduce fossil fuel consumption. These are considered in more detail below.

4.3.3.1 Electricity-saving measures

As there are no coal-fired power stations located in Durban, electricity is purchased by the city from the parastatal electricity supplier, Eskom. The supply of electricity to the city rose by over 25% during the period 1994 to 2004, with the industrial sector being the largest user of electricity in the city (EM, 2006).

Durban, similar to the rest of the country, has in recent years experienced electricity supply shortfalls with rolling blackouts since late 2005, which reached crisis levels in 2008 (Sebitosi and Pillay, 2008). This resulted in the interruption of supply of energy due to a lack of electricity to meet the demand, a process commonly referred to as load shedding (Büscher, 2009). In light of these electricity shortfalls, large industrial consumers of electricity were requested to reduce their consumption by 10% (EM, 2009*b*). A comparison of industrial electricity consumption in 2008 compared to 2007 shows that there was on average a 3% decrease in electricity consumption.

Those industries that managed to reduce their electricity consumption did so by conducting energy audits and identifying opportunities for reductions in electricity consumption. Specifically, measures such as improving lighting, and installing solar water heating for canteens and ablution facilities enabled significant reductions in electricity consumption. The electricity-savings have been well documented as successful energy-saving measures by the city. The reduction of electricity consumption in 2008 resulted in marked decreases in GHGs and some air pollutants (Table 4.4).

Table 4.4: Air pollution and GHG emission reductions (in tonnes) from electricity-saving measures in 2008 compared to 2007

Intervention	Savings (South African rands)	CO_2	SO_2	NO_x
Industrial electricity reduction	23 071 410	69913	608	307

In addition to these measures, there are other long-term projects, aimed at reducing electricity consumption to curtail costs, that have been initiated. Some industries in the city have begun to take advantage of opportunities to capture excess heat from primary combustion, for use as heat and power in a secondary process. This method of generating energy is commonly referred to as combined heat and power (CHP) or cogeneration. CHP is an option that allows for increased efficiency by removing or reducing the need for a fuel source in the second process. CHP provides a more energy efficient option than producing separate heat and power with the secondary benefit of reduced air pollution. However, the extent of the GHG and air pollution mitigation will vary according to the fuel used for primary energy generation and the air pollution controls that are implemented. Typical examples of CHP within the city include the recovery of steam which is fed back into the electrical system. In some instances it is reported that industries have been able to reduce electrical grid consumption by 10%.

It is important to recognise that whilst such electricity-saving measures result in lower atmospheric emission levels at the power plants, such measures can only contribute toward indirect GHG emission reductions for the city (Mestl *et al.*, 2005) in accordance with international protocols established to guide the development of local GHG emissions inventories (WRI, 2009). Furthermore, industries may be sceptical about investing in electricity reduction from the national grid as the air pollution benefits will not directly accrue to them. However, there are financial savings from reducing electricity consumption as shown in Table 4.4 and it further presents the opportunity to offset increases in GHG emissions due to air pollution interventions (discussed later).

4.3.3.2 Improving the efficiency of combustion systems

Combustion systems in industries represent a significant source of on site emissions. It is well established that measures such as reducing stack temperature can result in improvements in the efficiency of a combustion system such as a boiler (Jaber, 2002). Other options such as replacing old and obsolete boilers with new efficient ones (Einstein *et al*., 2001; Jaber, 2002), modifications to the boiler design to a multilayer combustion system and boiler management all have the potential to improve efficiency and thus contribute to significant emission reductions (Aunan *et al*., 2004).

Further, it has been found that the efficiency of boilers varies according to the fuel type that is used (Einstein *et al*., 2001). A combination of increased boiler efficiency and change in fuels has been shown to have significant co-benefits (Jou *et al.*, 2008). Thus a combination of improving boiler efficiencies together with certain fuel changes could lead to significant emission reductions.

Boilers used in the city of Durban are typically of the gas fire-tube or water-tube type and are estimated to be older than 30 years. On average, the combustion efficiency of the boilers is high, though the major fuel sources of the boilers include coal and MRG. Industries within the city have demonstrated that a thorough understanding of steam or heat requirements of specific processes can lead to more efficient use of the fuel that is used (EM, 2009*b*), and thus result in emission reductions.

A good example of this intervention is that of a chemical company in Durban that switched from using coal in its boilers to MRG. The industry further made changes to the boiler systems by replacing a 12t/hr at 10 bar water tube coal boiler that had an efficiency of 68% with a 30 t/hr at 13 bar gas fired tube boiler with an efficiency of 93%. The fuel switch from coal to MRG resulted in a power consumption reduction in the boiler house of 200 kW, with a reduction of 37% in CO_2 emissions and 81% in SO_2 emissions (NCP, 2008). Whilst this intervention was successful, it may not be easily translated to other industries, as the cost of the alternate fuel and retrofitting the boilers are important considerations.

4.3.4 Summary of the impacts of air quality and energy policies implemented by industries

In summary, interventions in the industrial sector in Durban stem from the implementation of air quality policy, aimed at improving ambient air quality, and implementation of the city's energy strategy, designed to reduce energy consumption through improving energy efficiency. Although closely linked, air quality and energy policies in the city are being executed independently, without consideration of the trade-offs or synergies for climate change and air pollution respectively. In the case of air quality, the reduction of SO_2 emissions has been of critical importance for human and environmental health in the SDIB. However, the installation of end of pipe technologies and switching to fossil fuels with lower sulphur contents has allowed industries to continue to use fuel sources such as coal and refinery gas, which are significant contributors to CO_2 emissions in Durban (Table 4.3). Reduction in electricity consumption by industries has been prioritised by the city's energy strategy, despite being responsible for only a third of CO_2 emissions from this sector. Energy-saving measures thus have not been aligned with the city's AQMP nor promoted for the co-benefits that may be achieved.

4.4. The role of legislation in promoting co-benefits and the potential impact of future air pollution control on climate change

There are often multiple legislative drivers (Taylor, 2006) that influence the approach that an industry will take to improve its environmental performance. The types of regulations implemented may impact on an industry's decision to adopt air pollution control technologies or undertake changes to its operations (Khanna *et al.*, 2009). A total replacement of end-of-pipe technologies by cleaner production or structural measures is certainly not possible. In practice there will always be a mix of end-of-pipe technologies and cleaner production (Frondel, 2004). A key determining factor in the approach taken by an industry could be the timeline to expected emission reductions and the cost-effectiveness of meeting legislated targets. Of critical importance is that there is likely to be a significant time lag for an industry to develop an air pollution control plan and then effectively implement it.

Command and control policies are thought to impose regulatory frameworks with compliance timetables that can only be met through end-of-pipe abatement measures, preventing the adoption of in-plant cleaner production (Frondel, 2004; Taylor, 2006). The role that air quality regulations play in initiating innovative approaches to air pollution control, will be critical in determining if industries in Durban are successful in adopting air pollution measures with co-benefits for climate change. Lessons learnt from the reduction of SO_2 emissions in the city and energy efficiency improvements made by industry indicate the trade-offs and synergies of interventions that can be used to guide future interventions in this sector. The implications of new emission standards under the AQA and expected changes to fuels produced in South Africa are considered below.

4.4.1 New emission standards under the AQA

The AQA has defined requirements for industries to meet emission standards for new and existing plants which could present significant challenges to achieving co-benefits. In light of new emission standards, the focus of future emission reduction projects by industries in the city is likely to be on NO_x and PM emissions. Tables 4.5 and 4.6 show the impact of replacing the higher polluting fuels such as coal and refinery gas, with other fuel sources such as MRG and biomass.

Table 4.5: The impact on air pollutant and greenhouse gas emissions (tonnes per annum) of replacing coal used in industry with MRG and biomass

	CO_2	**SO_2**	**NO_x**	**PM**
Coal	1 810 427	10 919	5409	2957
MRG	1 145 783	38	3265	62
Biomass (wood)	0	958	1915	22091

Table 4.6: The impact on air pollutant and greenhouse gas emissions (tonnes per annum) of replacing refinery gas used in industry with MRG and biomass

	CO_2	**SO_2**	**NO_x**	**PM**
Refinery gas	1 501 218	124	1052	63
MRG	1 375 653	46	3909	74
Biomass (wood)	0	1150	2230	26522

Due to the presence of paper and pulp mills in the city, an attractive option from the perspective of industrial climate change mitigation is the use of renewable energy sources such as wood in boilers and furnaces. Biomass is generally viewed as being carbon neutral as the CO_2 released from the fuel when burnt is equivalent to the amount of CO_2 taken up by the tree during its lifetime. Biomass usage may thus mitigate further CO_2 emissions. However, the method by which the energy from biomass sources is extracted could have implications for air quality as demonstrated by policy in the United Kingdom, which promoted the usage of wood chips in biomass boilers and in so doing offset the air quality improvements from air pollution specific control measures (Hayes *et al*., 2008).

In the case of the AQA, the combustion of wood biomass would be required to meet the same PM and NO_x emission standards as is the case for other solid fuels. Thus, promoting the use of biomass in boilers could offer co-benefits, if standards for PM emissions are well regulated.

There are other factors, however, that will influence an industry's decision. The costs of fuels (Table 4.7) and the structural changes that would be required are likely to be key determining factors. Many of the larger manufacturing/process industries are already established in the city and have been designed to operate using specific raw materials. To meet the emission standards for existing plants, industries may opt to retrofit technologies to reduce emissions. The new legislation for NO_x and PM emissions under the AQA could thus result in industries opting to use end-of-pipe technologies as opposed to fuel switching or structural changes, with significant implications for climate change.

Table 4.7: Typical costs of different forms of energy (AES, 2010)

Type of energy	**Costs (Rands/GJ)**
Refinery Gas*	0
Coal	25.5
MRG	35-60
Heavy fuel oil	74

*Currently only used at petroleum refineries, where it is produced as a waste product, thus incurring no direct costs

NO_x control options such as fluidized bed combustion represent a convenient option to reduce NO_x and PM emissions. However, it has been shown that such measures could actually increase nitrous oxide (N_2O) emissions. Selective catalytic reduction (SCR), another commonly used measure in stationary combustion appliances, reduces NO_x but also has emission by-products that include ammonia (NH_3) and N_2O (Winiwarter, 2005). The installation of electrostatic precipitators (ESP) is another common end-of-pipe device used to reduce PM emissions, but also has the effect of reducing the efficiency of the plant. As has been noted in respect of SO_2, the installation of end-of-pipe technologies and switching to lower polluting fuels does not offer long-term solutions that benefit climate change. However, these pollution control technologies are regarded as being critical to prevent compromising economic growth (Hammar and Löfgren, 2010), which is particularly relevant within the context of a city in a developing country.

4.4.2 Clean fuels programme in South Africa

Globally, stricter regulations are being implemented to lower the sulphur content of petroleum products with concurrent development of advanced vehicle technologies. Petroleum refineries in countries such as those in Australia have reported increases in CO_2 emissions as a result of adapting their refineries for the production of petroleum products with lower sulphur content. According to DEFRA (2007), such increases in CO_2 emissions at refineries could be offset by improved technologies in petrol vehicles, though this is not robustly understood within a developing world context.

It is widely anticipated that within the next 10 years the South African government is likely to implement Clean Fuels 2 specifications (SA, 2003). This will require further reductions to the sulphur content of diesel and petrol that is manufactured in the country. The Clean Fuels initiative is seen as an imperative for reducing road transport-related emissions, as it will allow for the manufacture of petroleum products that contain less harmful air pollutants. It will further permit the introduction into the country of motor vehicles with advanced pollution control technologies and allow existing motor vehicles with such technologies to operate more efficiently. As Durban has two operating petroleum refineries within its jurisdiction, the climate change impact of implementing changes at industrial sites to facilitate the refining of cleaner fuels needs to be considered.

In order to meet these new fuel specifications, capital and operational costs at petroleum refineries in the city would be expected to increase. The current desulphurization techniques for petroleum products use significant amounts of hydrogen, which is an energy intensive product, with higher energy consumption and higher emissions of CO_2 also occurring (Szklo and Schaeffer, 2007). Specifically, the installations of equipment such as hydrocrackers are likely to be required. There are some uncertainties as to whether these increases in CO_2 are experienced only in the short-term or will continue throughout the operation of the plant.

In order to avoid increases in CO_2 emissions, it is suggested that alternative desulphurization techniques such as biodesulphurization and oxidative desulphurization could be used. The use of biodesulphurization techniques can produce 70-80% lower CO_2 emissions than conventional methods, and has lower operational costs (Soleimani *et al*. 2007), however the use of such techniques still face some challenges.

Expected CO_2 emissions increases from these process changes can only be determined once the Clean Fuels 2 emissions standards are released and the petroleum refineries are able to assess how it will affect their operations and energy consumption. From the experience of implementing the first phase of this project, namely Cleans Fuels 1, it is estimated that the annual CO_2 emissions from the petrochemical refineries in Durban increased by over 8% (Fig. 4.1).

The timing of the introduction of cleaner fuel standards in South Africa has to be assessed carefully according to the likely impacts on refinery emissions and the time delay in seeing an effect in the road transport sector due to the ageing motor vehicle fleet. Further, this needs to be considered alongside the AQA requirements for PM and NO_x emission reductions required by these industries, taking cognisance of where the maximum benefit for the environment can be achieved and thus prioritised for investment.

4.5. Combining energy policies and air quality interventions to support a low-carbon society

Worrel and Price (2001) raise an important point, that industrial policies are never implemented in isolation, as individual policies may have feedback effects, which can impact on the effectiveness of other policies. An understanding of the impact of the air quality control strategies on other air pollutants and GHG emissions is necessary for stakeholders to select and implement those air quality control measures that can support GHG mitigation efforts and avoid those that may act to offset the GHG reductions obtained from energy or climate change specific mitigation strategies.

Industries may take different routes to meeting air quality targets. These can vary from a minimalist approach that seeks to reduce any trade-offs for climate change, to one that maximises any synergies that may be present within the system and avoids trade-offs. With the former approach, if an air pollution intervention results in increases in GHG emissions, measures should be taken to offset this (Fig. 4.2). In such a case if an industry decides to install an end-of-pipe technology, it may offset the increases in energy consumption by improving energy efficiency elsewhere within the plant. An energy loss management system for example could be implemented to ensure that the industry is fully aware of opportunities within the plant to offset the impacts of its air quality actions.

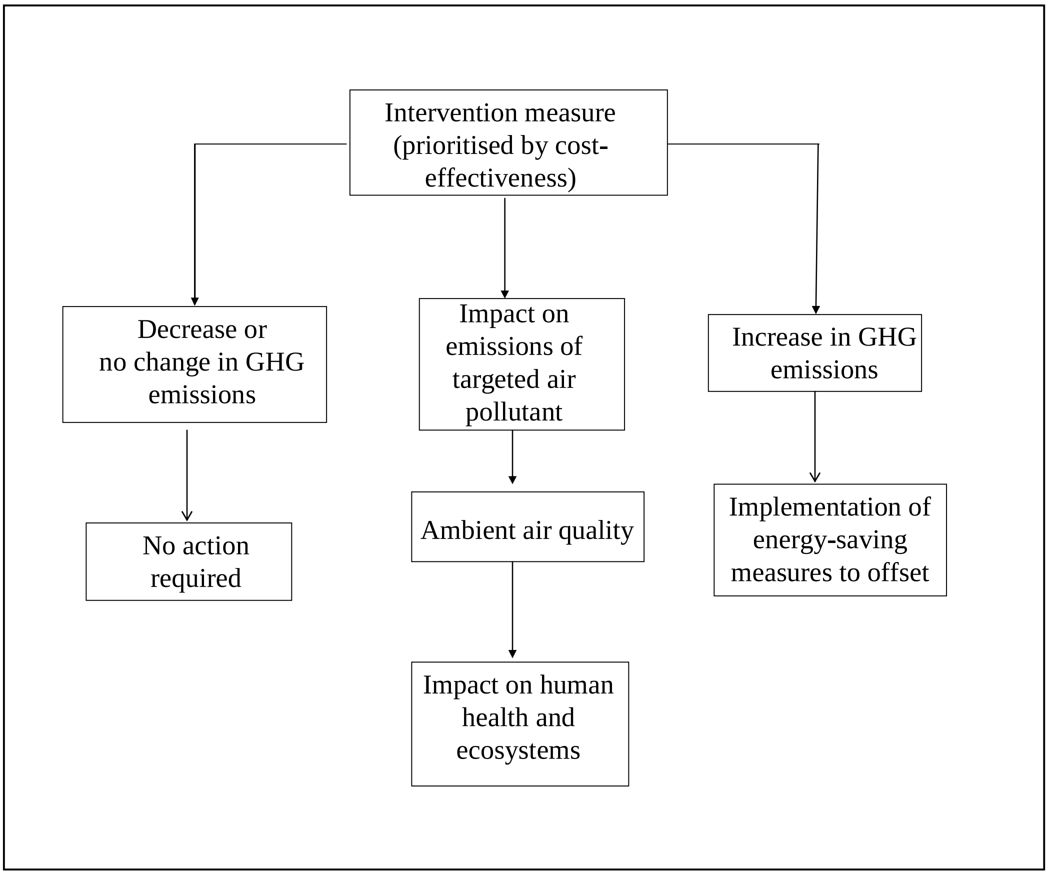

Figure 4.2: Minimalist approach to achieving co-benefits for climate change mitigation from AQM interventions

However, if the industry wants to maximise any synergies and best utilise opportunities to simultaneously reduce its carbon footprint through its air quality initiatives, it will have to consider the impact of the intervention for the targeted pollutant and other atmospheric emissions, and the overall impact for climate change (Fig. 4.3). When selecting an intervention measure to meet air quality targets, there need to be criteria in place to ensure that the complex climate change linkages and interactions that exist between these two issues are considered. Measures selected will have to focus on switching to lower carbon fuels and improving industrial efficiency. This will be especially relevant to those new industries that are designing their plants to achieve the prescribed emission limits for air quality. Industries that undertake air quality interventions that verifiably mitigate GHG emissions should be credited for early action once specific GHG mitigation policy is implemented in the city.

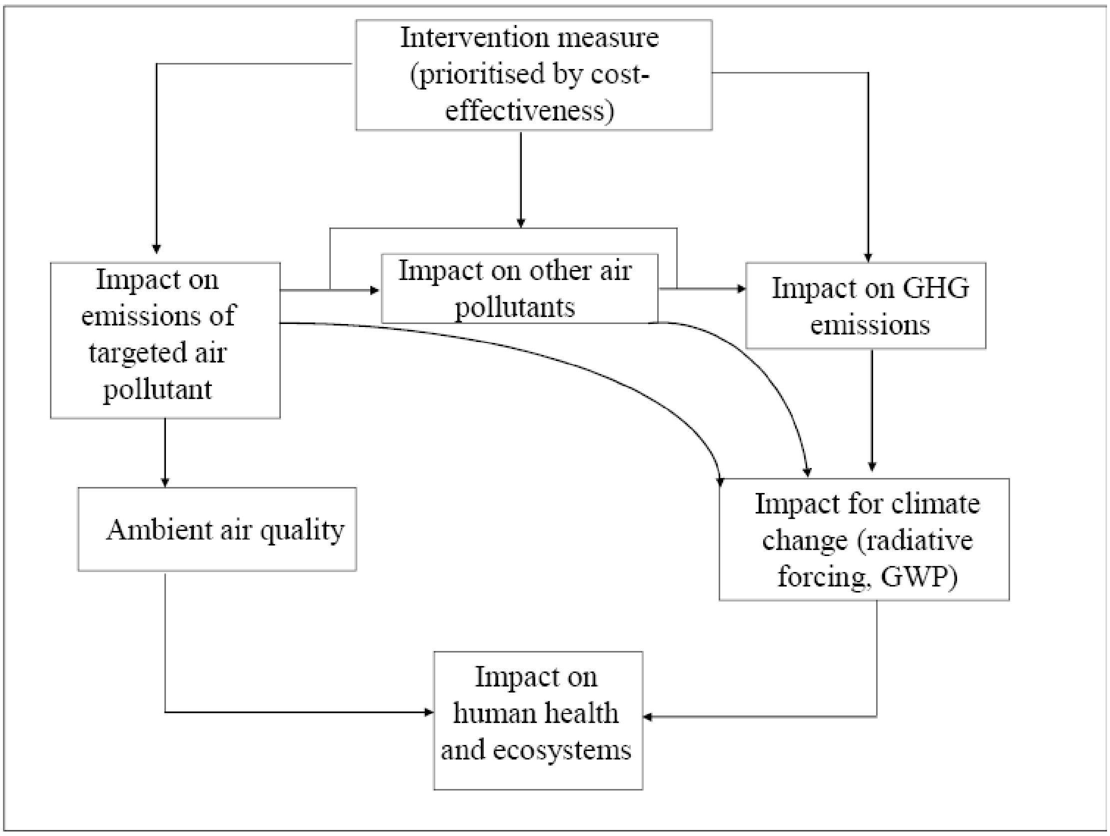

Figure 4.3: Maximist approach to achieving co-benefits for climate change mitigation from AQM interventions

4.6. Discussion and concluding remarks

Energy consumption is one of the important sources of GHG emissions within the industrial sector. However, the primary concern of industries has been dealing with air pollution and being compliant with other legislation that may apply to their operations. As GHG emissions are not regulated by any specific national legislation or by-laws within the city, there has been little incentive for industries to focus on reducing GHG emissions through measures targeted at improving air quality. Therefore, industrial measures that have contributed toward GHG mitigation have been primarily as a result of fuel switching and energy-savings.

New air quality related legislation applicable to industries has the potential to impact on GHG emissions. Measures taken to ensure compliance with new emission standards should ideally have co-benefits for simultaneously reducing GHG emissions. If this is not the case, industries should ensure that measures to offset GHG increases from air pollution measures are implemented. In addition, it must be borne in mind that the benefits of reducing fossil fuel consumption on site will result in direct air quality benefits and GHG emission reductions. The city thus has a responsibility to promote or incentivise investment in onsite energy combustion efficiency. This is especially relevant in areas of the city where industries are located in proximity to residential areas and ambient air quality standards are currently being, or could potentially be exceeded. Finally, at higher spheres of government, action needs to be taken to set up a regulatory framework to promote the adoption of air quality measures with co-benefits. Industries that have or will undertake air quality interventions that verifiably mitigate against GHG emissions should be credited for early action once specific GHG mitigation policy is implemented in the city.

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CHAPTER 5:

THE CASE FOR INTEGRATED AIR QUALITY AND CLIMATE CHANGE POLICIES

Abstract

The relationship between air quality and climate change provides a scientific basis for developing integrative policies. Local governments in developing countries are expected to reap significant benefits from incorporating climate change concerns into air quality policies. In Africa, South Africa is also one of the few countries on the continent to have developed robust air quality legislation. South African municipalities or local governments are required to develop and implement air quality management plans (AQMPS), which present opportunities to integrate climate change considerations. The extent to which cities are currently incorporating climate change concerns into existing air pollution strategies, and the opportunities for improved integration of these two issues, and actions to support the implementation thereof, are presented in this chapter using the city of Durban as a case study. The results from this case study suggest that in the short-to medium-term, local AQMPs can be used to support climate change mitigation. These outcomes could be relevant to other countries that use a similar approach to air quality management and require local AQMPs to be developed.

Keywords: a*ir quality management; climate change mitigation, integrated policies, Durban*

5.1. Introduction

Air quality and climate change are inextricably linked, with complex interactions and linkages. This relationship provides a scientific basis for developing integrative policies that derive multiple benefits for simultaneously improving air quality and addressing climate change. As the focal points of expected growth in polluting activities (Fenger, 2009), cities in developing countries have the potential to act as 'engines of environmental policy' (Granberg and Elander, 2007, 439), and to drive innovative policy responses to climate change, whilst simultaneously addressing urgent air pollution challenges. Based on recent climate negotiations, early policy development and planning for climate change within air quality management (AQM) polices may position cities to capitalise on opportunities to reduce baseline greenhouse gas (GHG) emissions, lead in future efforts related to the carbon trading market, and thus contribute toward creating low carbon, resilient societies.

On the African continent, South Africa is one of the few countries to have developed robust AQM legislation and air quality monitoring programmes (APINA, 2010). The South African National Environmental Management: Air Quality Act (*Act No.39 of 2004)* (the AQA) ensures that cities are well capacitated with authority over air quality through the development of local air quality management plans (AQMPs). Presently, AQM proceeds through the implementation of the most cost-effective actions to reduce air pollution, with the costs of interventions generally increasing until targets for emission reductions are achieved. However, the AQA does not provide guidance for the integration of climate change concerns into local AQMPs. Opportunities to use air quality interventions in an innovative manner to contribute toward creating low carbon, resilient communities are therefore mostly overlooked. South Africa is ideally poised to develop holistic AQMPs that incorporate climate change considerations. This will not only set an example for many developed countries with similar AQM structures but may also provide some guidance for other African countries who are still developing their air quality policies.

The purpose of this chapter is to discuss the role that local AQMPs in South Africa can play in supporting climate change mitigation and adaptation endeavours, using the city of Durban as a case study. The extent to which the city currently incorporates climate change concerns into its existing AQMP, and the opportunities for improved integration of these two issues is presented in Section 5.2 of this chapter. In Section 5.3, key recommendations for decision-makers to consider in facilitating the inclusion of climate change into local AQMPs are presented. Section 5.4 presents concluding remarks.

5.2. Case study of Durban

5.2.1 Background to air quality and climate change issues

Durban is located within the province of KwaZulu-Natal on the eastern seaboard of South Africa. It occupies ~1.4% of the total area of the province and has the largest port on the east coast of Africa. The city’s economy is driven by manufacturing industries and tourism, comprising 9% of South Africa’s Gross Domestic Product (GDP) and represents the third largest economy in the country (EM, 2010). The economy has been shaped principally by an energy sector that is dependent primarily on the use of the country's large coal reserves and liquid fuel imported as crude oil. The manner in which energy is generated and consumed is the source of many environmental challenges, including poor ambient air quality and high GHG emissions. Both of these are discussed in more detail below.

5.2.1.1 Air pollution

Durban has been characterised as consisting of numerous air pollution sources, primarily attributed to the combustion of fossil fuels at industries and in road transport. The AQMP developed in 2007 serves as the foundation to ensure that measures are implemented within these sectors to maintain ambient air quality levels that are acceptable for human health and ecosystems (EM, 2007*a*).

The city has a modern air quality monitoring network, consisting of 11 air pollution stations. Annual averaged data from these continuous air quality monitoring stations indicate that the ambient air quality experienced in the city is generally within the South African standards for ambient air quality (Fig. 5.1).

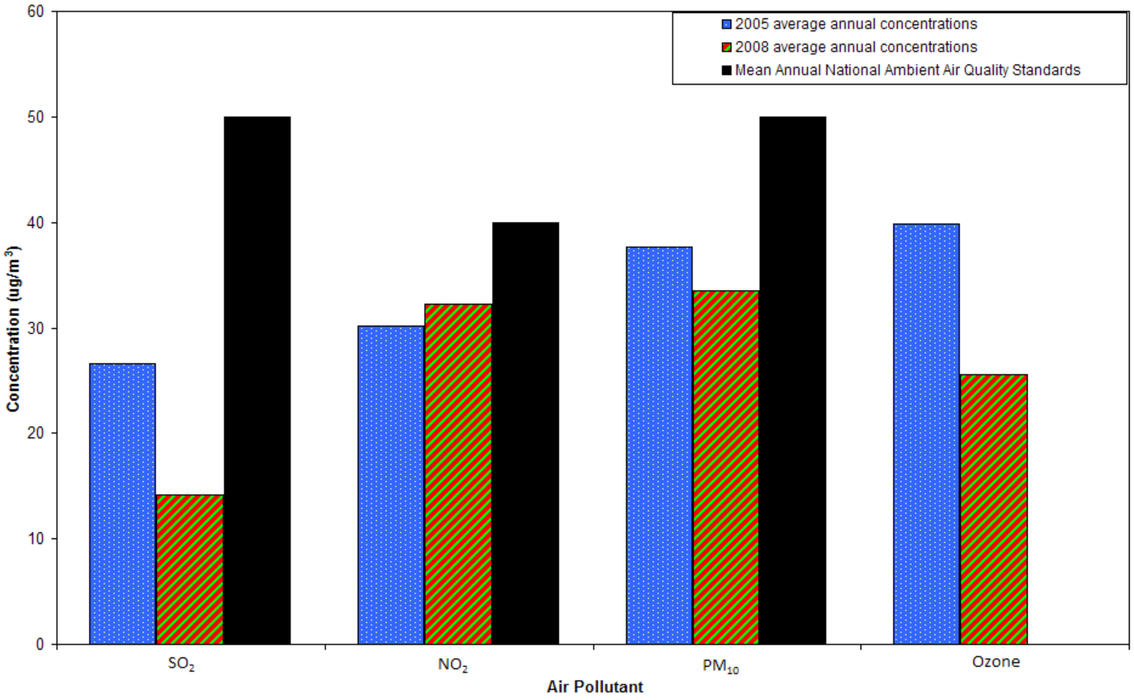

Figure 5.1: Average annual priority pollutant concentrations for 2005 (EM, 2005) and 2008 (EM, 2008) versus annual ambient air quality standards (SA, 2009). * There is no annual standard for ozone

Levels of average annual particulate matter (PM_{10}) and nitrogen dioxide (NO_2) shown in Figure 5.1 are indicative of the growing contribution of road transport emissions. Conformity with sulphur dioxide (SO_2) limits is primarily due to the impact of past industrial interventions focused on SO_2 emissions. Although these data indicate compliance in terms of mean annual standards, in recent years the 10-minute and hourly limits for ambient SO_2 have been exceeded (EM, 2008). These exceedances were primarily linked to industrial process upsets, flaring incidents and downtime of air pollution scrubbers in industries. The frequency of these exceedances has been a strong focus of the city and industries for reduction. In light of new minimum emission standards being implemented under the AQA, PM and NO_x emissions are also likely to be the focus of future AQM action plans.

5.2.1.2 Climate change

Climate change concerns have to date been dealt with separately from the AQMP with the majority of research focused on understanding the impacts of climate change on the city and the adaptation measures that will be required. This has been a priority as it has been estimated that in the future (2070 to 2100) the city will experience varied climate change impacts. These changes are likely to exacerbate the problems of the poorest communities, who are least likely to be able respond or adapt.

Two GHG emissions inventories have been developed for the years 2002 and 2005 (EM, 2003; EM, 2007*b*). The 2005 emissions inventory highlighted electricity consumption as the major contributor to emissions, followed by contributions from industries and road transport. It was also estimated that the direct combustion of fossil fuels (excluding electricity consumption) in the road transport and industrial sectors were cumulatively responsible for ~46 % of the total GHG emissions.

On a per capita basis, the GHG emissions of Durban are lower than those of other cities with similar populations (Table 5.1). The higher emissions per capita for these cities can be attributed to various factors based on the characteristics of the city, including affluence and the sources of energy, as well as the methodologies used for developing the inventories.

In the case of Durban, many sources of emissions were not covered in the GHG inventory. These include the direct and fugitive contributions from the industrial sector, emissions related to shipping activities, and natural sources of emissions. In addition, estimates of road transport emissions were based on fuel sales and further, no assessment of emissions related to the life-cycle of goods manufactured and used in the city was made.

Table 5.1: Comparison of Durban's per capita emissions to other cities

City	Year of Inventory	Population	Carbon dioxide equivalent (CO_2-eq) estimates (M tonnes) per annum	Per capita emissions (tonnes/capita)
Athens	2005	3 989 000	41.47[a]	10.40
Frankfurt	2005	3 778 124	51.61[a]	13.66
Hamburg	2005	4 259 670	41.52[a]	9.747
Bangkok	2005	5 6 58 953	60.44[a]	10.68
Cape Town	2006	3 497 097	40.43[a]	8.65
Durban	2005	3 161 844	23[b]	7.27

(Sources of data: [a] Kennedy *et al*., 2009; [b] EM, 2007*b*)

5.2.2 Climate change considerations and the AQMP

It has been argued that climate change considerations can potentially be included throughout the development and implementation of AQMPs in South Africa (Thambiran and Diab, 2010*a*), thus providing a platform to develop integrative policy responses to climate change. However, internationally, it has been shown that whilst local authorities may have the potential to promote the adoption of climate change considerations through this control of critical functions and existing policies, there have been many barriers to overcome. These range from a lack of awareness of opportunities, competing priorities and a lack of community/political will to act (Burch, 2009).

In the case of Durban, climate change and air quality issues are dealt with separately. Opportunities to use air quality interventions innovatively to address GHG emissions are therefore mostly overlooked. The opportunities for the city to start taking cognisance of the complex atmospheric interactions and linkages that exist between these two issues (Fig. 5.2) are discussed further in this section.

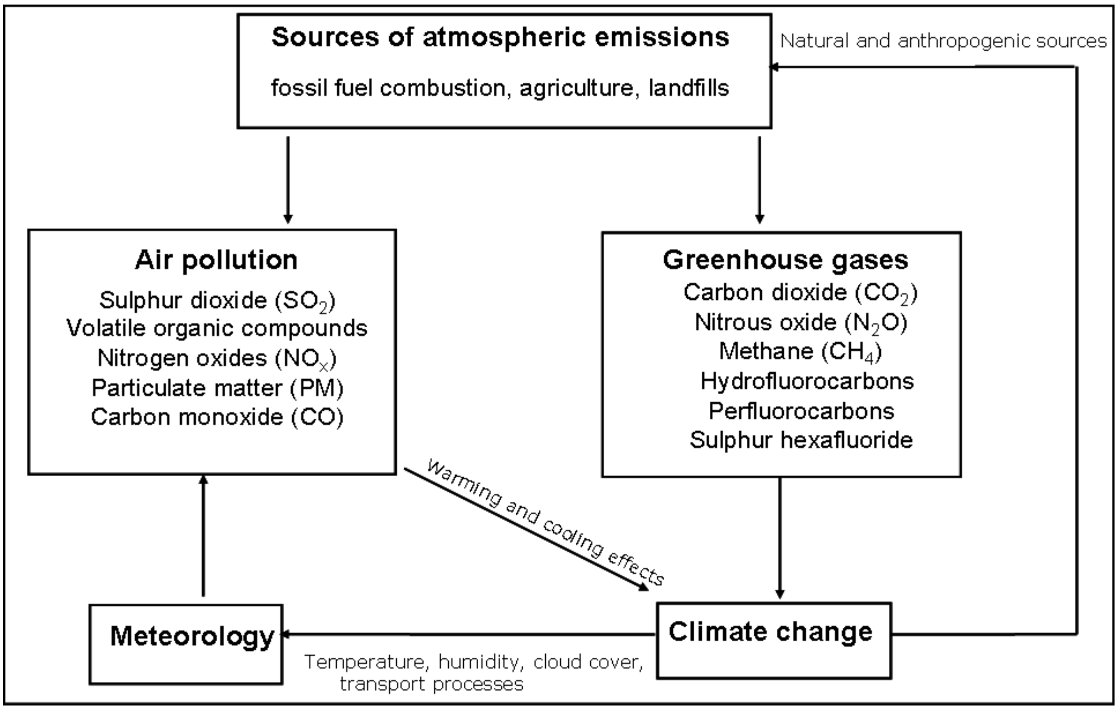

Figure 5.2: Summary of the linkages and interactions between climate change and air quality

5.2.2.1 Atmospheric emission reductions

Climate change and air quality considerations share common sources of emissions, thus interventions in these areas can simultaneously affect more than one air pollutant. A measure targeted at reducing emissions of a particular pollutant, might result in increases (trade-offs) or decreases (synergies or co-benefits) in the emissions of other pollutants. The combustion of fossil fuels within the industrial and road transportation sectors in the city is one of the most significant contributors to air pollution and GHG emissions. Both these sectors are prioritised for intervention in the AQMP, with no air pollution control measures currently being implemented within the road transport sector. There are no interventions within either of these sectors that are directly targeted at reducing GHG emissions.

In previous work by the authors (Thambiran and Diab, 2010*b*; 2011), emission inventories for 2008 for the industrial and road transport sectors in the city were developed. It was found that in 2008 the contribution to GHG emissions from these sectors increased by ~10% compared to 2005, thus indicating a growing contribution of GHG emissions from these sectors. The emission inventories were further used to characterise how the different components that contribute toward atmospheric emissions in these sectors are related and how they could potentially be manipulated to achieve co-benefits. In this section, the outputs of an analysis of co-benefits are considered qualitatively within the context of possible impacts for other key priorities in the city.

The industrial sector

The industrial sector in Durban has been regulated up until 2010 by the Atmospheric Pollution Prevention Act (*Act No. 45 of 1965*) (the APPA), with many of the major industries being required by the local government to adopt more stringent emission standards as part of a set of measures to improve ambient air quality in the south of the city. In Thambiran and Diab (2010*b*), these air pollution interventions were considered in terms of their impacts on GHG emissions. It was found that the local government has required the implementation of numerous actions by industry to address air quality concerns and that these measures have been accompanied by varying synergies and trade-offs for climate change (Table 5.2). These include the increase in energy consumption due to the installation of air pollution cleaning devices and co-benefits from fuel switching. The impact on GHG emissions was not quantified or considered in the decision to implement these air quality control measures. Consequently in instances where interventions resulted in increases of GHG emissions, no actions were taken to offset the trade-offs for climate change.

Table 5.2: Impact of industrial interventions on atmospheric emissions and fossil fuel consumption within Durban (Thambiran and Diab, 2010*c*)

Industrial measure	**Emissions increase**	**Emissions decrease**	**Impact on fossil fuel consumption**
Installation of cleaning devises	CO_2 N_2O	SO_2 or PM or NO_x (depends on type of device used)	+
Modification to cleaning devices	CO_2	SO_2 or PM or NO_x	+
Change in fuel toward cleaner more efficient fuels		Reduces all related emissions from original fossil fuel source	-
Change in fuel toward use of renewable energy	PM, NO_x	CO_2, SO_2	-
Change high sulphur coal to low sulphur coal		SO_2	No change. Increase if capacity requirements increase
Boiler modifications		Increases efficiency, reduces all air pollutants related to fossil fuel	-
Energy efficiency measures		Reduces all related emissions from fossil fuel source	-

+ (-) indicates an increase (decrease) in fossil fuel consumption

In addition to air quality improvements, industries have also implemented numerous energy-saving measures predominantly focused on reducing grid-supplied electricity. This has had no direct co-benefit for air quality improvements within the city. These interventions were implemented as a result of cost-savings measures on the part of the industry, and demand-side management as required by the local government. Thus interventions employed for AQM and energy strategies are uncoordinated and therefore do not maximise opportunities for co-benefits.

In order to achieve co-benefits, energy strategies and AQM planning need to be co-ordinated with respect to industrial interventions. The AQMP needs to have mechanisms in place to promote the adoption of air quality measures with co-benefits for GHG mitigation over those with trade-offs. Industrial activities that are regulated through atmospheric emission licenses (AELs) under the AQA present an opportunity to regulate co-benefits.

It is proposed that the quantification and consideration of the impact of air quality interventions for GHG emissions should be included as a condition for the issue of an AEL. Specifically, the impact of an air quality intervention on energy consumption and GHG emissions could be included when granting, reviewing and renewing an AEL. The expected increase or decrease in GHG emissions from an air quality measure should be quantified. If it results in increases in GHG emissions, measures that will be taken to offset this should be detailed in the application. Industrial energy audits may, for example, be used by industries to help identify other areas of operation where improvements to energy consumption could offset these increases. In cases of verifiable GHG emissions reductions, frameworks to adequately recognise and reward these efforts should be implemented through measures such as rebates of AEL application fees. Regulating air quality inventions that have favourable outcomes for GHG emissions through the AQA would require changes to national legislation. Alternatively, the local government could be proactive in this regard, by developing municipal by-laws requiring that industries prioritise those air quality interventions that are characterised by co-benefits.

However, there are numerous industries that are not categorised as listed activities and therefore do not require AELs. The cumulative contribution of fugitive and process emissions from these industries could have significant environmental consequences. Regulating air pollution and GHG emissions within non-listed industrial activities is an area that should be addressed across all spheres of government. Municipal by-laws could be established regulating the permissible emissions from non-listed industrial activities.

A combination of AELs and municipal by-laws can therefore be used to regulate the implementation of air quality control measures such that the trade-offs as shown in Table 5.2 are avoided or minimised. The industry's overall contribution to GHG emissions (within the city/nationally) and its emission intensity can be used to guide acceptable levels of trade-offs from an air quality intervention measure.

The road transportation sector

The road transport sector is considered to be a growing source of air pollution in the city. Unlike the industrial sector, regulations for the road transport sector are not as well developed within the country, with little incentive to ensure that motor vehicles are low contributors to air pollution. Many of the measures that are typically proposed to address air pollution within this sector have the potential to simultaneously impact on road safety and fossil fuel consumption as shown in Table 5.3.

Table 5.3: Impacts of road transport interventions on atmospheric emissions, fossil fuel consumption and road safety within Durban (Thambiran and Diab, 2010*c*)

Transport Intervention	**Impact on emissions**	**Impact on fossil fuel consumption**	**Impact on road safety**
Fleet renewal	Decrease of PM, NO_x (diesel vehicles) and CO (petrol vehicles). Impact on other pollutants depends on vehicle kilometres travelled (VKT)	- (improve fuel efficiency of newer vehicles) + (increase in VKT by newer vehicles)	-/+
Promotion of ultra-low sulphur diesel	SO_2 decreases Reduction of ultrafine particles of black carbon	No impact	No impact
Reducing congestion	Decrease in all emissions due to lowering of VKT	-	-
Uptake of biodiesel	Decrease CO_2 Increase: PM, NO_x	-	No impact
Promotion of public transport over private motor vehicle use	Reducing VKT and all related emissions	-	-
Raise awareness of energy efficiency	Reducing VKT and all related emissions	-	-
Increased efficiency of freight transport system	Reduction in all emissions related to road freight transport due to reduced VKT	-	-

+ (-) indicates an increase (decrease) in fossil fuel consumption; + (-) indicates no benefits (benefits) for road safety

The AQMP can play an important role in ensuring that interventions with multiple benefits are selected, by supporting and influencing interventions that target the types of vehicle technologies, fuel changes and road transport management measures that are implemented in the city. Further details are provided below.

Motor vehicle technologies and fuel changes

The age of the motor vehicle fleet within the city indicates that a large proportion of motor vehicles have been purchased prior to legislative controls on motor vehicle emissions in South Africa (Thambiran and Diab, 2011). Since it is widely recognised that it is difficult to retrofit older motor vehicles with catalytic converters and particulate diesel filters, it is necessary to try to reduce the numbers of these older motor vehicles on the road.

Notwithstanding this overall imperative, the replacement of older motor vehicles with new, less polluting ones may have varied impacts for air pollution depending on whether a petrol or diesel motor vehicle is purchased as shown in Table 5.3. Furthermore, as older motor vehicles are generally driven less, fleet renewal may result in an increase in vehicle kilometres travelled (VKT), thus potentially offsetting atmospheric emission reductions achieved through the use of improved pollution control technologies.

Policies aimed at influencing the types of motor vehicles purchased, specifically the split between petrol and diesel motor vehicles will therefore influence emissions from road transport. As such, AQM considerations should guide the types of motor vehicles promoted based on the likely overall impact on atmospheric emissions. Any fleet renewal campaign within the city will require an atmospheric emissions impact assessment and should be supported by measures to manage VKT (discussed later).

However, the ability of the city to actually influence the purchasing decisions of private motor vehicle owners may well be minimal and even if achievable, the impact would be confined to motor vehicles registered within its jurisdiction. A similar argument related to the city’s limited ability to influence road transport users applies to making biodiesel or lower sulphur fuels available for use in road transport. The concern here is that even if fuel-based programmes are initiated by higher spheres of government, they may not result in co-beneficial outcomes within the city as the passenger motor vehicle fleet is still predominantly petrol-driven and there is a poor characterisation of the extent of import and export of fuel by motor vehicles driven on roads within the city.

Transport Demand Management (TDM)

TDM involves decreasing the actual number of motor vehicle trips and encouraging people to switch from private motor vehicles to public transport or non-motorised activities such as walking and cycling. Numerous barriers to successfully implementing TDM exist. Specifically, educating people about the financial and environmental effects of their private motor vehicle use is often not enough to encourage them to change modes of travel, as 'psychological dissonance' generally occurs (Poudenx, 2008). This means that while people may realise their impacts of driving, they choose to downplay the negative implications of their actions, so that they may continue with their normal behaviour patterns. Motor vehicles are also commonly seen as a sign of status, making it more difficult to get owners to give them up and switch to other forms of transport. Furthermore, as the current public transportation fleet is not the preferred mode of transport in the city, the provision of a service of perceived higher quality that operates with clean vehicle technologies and fuels presents a significant challenge.

In cases where such impediments to promoting the use of public and alternate forms of transport exist; taxes, user road pricing or congestion charging are seen as useful short-term interventions. Taxes or 'feebates' on yearly vehicle registrations are based on annual average mileages and are used to encourage fewer trips and reduce the amount that motor vehicles are driven (Greene *et al.*, 2007). Disincentives to reduce traffic on congested roads have also been shown to be effective. A good example of a successful congestion charging policy is that of the Greater London Authority which led to a reduction in CO_2 emissions by 16% and generated over £93 million in revenue (EEA 2008).

AQM processes potentially have an important role to play in congestion charging, through assigning emissions to roads and determining impacts for ambient air quality. An important step to facilitate a better characterisation of emissions on roads is to improve the quality and frequency of road traffic counts. Improved spatial and temporal traffic count data, coupled with appropriate motor vehicle emission factors will allow for the determination of areas of significant emissions. Air quality monitoring data or dispersion modelling can be used to determine the impact on ambient air quality and the potential impacts for human health. This can be used as a basis for identifying those areas or roads that are in need of intervention and financial mechanisms to reduce travel in these areas may be considered. These measures however, will need to be supported by well-structured implementation plans and the development of efficient, safe and low polluting public transportation.

Heavy-duty vehicles

Durban's energy strategy and integrated transport plan both cite the need to encourage greater use of rail freight to reduce the demand for road freight transport. In an effort to promote greater use of the rail system the national government has issued plans to reduce the maximum truck axle limits from 9 tons to 8 tons (Cokayne, 2009). However, in the long-term the use of the rail system, which is primarily dependent on fossil-fuel generated electricity, is considered unsustainable (SA-ASPO, 2008).

Many of the problems with heavy-duty road freight transport are associated with operational problems related to overloading, motor vehicles being poorly maintained and exceeding the speed limit (Nordengen, 2009). The national road freight quality system requires permits for transporting goods, however, this system is poorly enforced and as such self-regulation of the heavy-duty vehicles used for freight transport is growing. A national standard for self-regulation within the heavy-duty motor transport fleet is under development. Many of the principles that underpin this standard such as load control and vehicle maintenance can contribute toward reduced fuel consumption and hence reduce atmospheric emissions.

Durban's integrated development plan (IDP) further proposes the development of a logistics platform to co-ordinate and facilitate freight movements to make more efficient use of freight transport options (EM, 2009). This logistics platform in conjunction with the road transport management standard can assist in encouraging more fleet operators to adopt measures to improve efficiency. However, a more legislative-based approach can also be taken. Specifically, emissions standards for on-road heavy-duty vehicles could be implemented, thus forcing the transformation of vehicles in this sector. The proposed emissions standards for medium and heavy-duty vehicles in the United States of America, which incorporate the weight of payloads is a good example of this (US-EPA, 2010).

5.2.2.2 Air quality and climate change feedbacks

Climate change and air quality issues are further intrinsically linked through complex atmospheric feedbacks that need to be considered within an AQMP. Specifically, SO_2, NO_x and PM impact on the earth's radiative forcing through short-term cooling and warming effects. Air pollutants further act to influence the lifetime and concentration of pollutants in the atmosphere. For example, an air pollution intervention measure may decrease NO_x emissions, but may have other impacts on pollutants that influence the climate, which in turn could have complex feedbacks as shown in Figure 5.3 below.

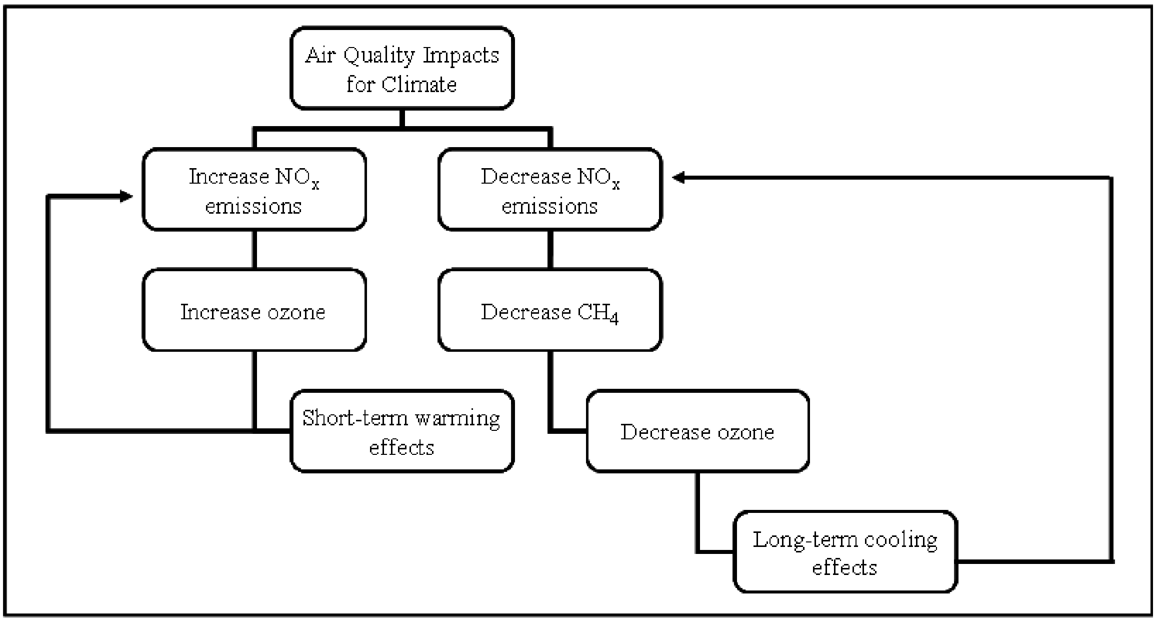

Figure 5.3: Air quality and climate change feedbacks associated with changing NO_x emissions

The reduction of NO_x would thus seem to offer favourable results for both air pollution and climate change. For other pollutants such as SO_2 the decision becomes more complicated, which could promote the increase of air pollutants in support of climate cooling. Thus policies that focus on this possible benefit for climate may result in 'perverse incentives to increase emissions and degrade air quality' (Rypdal *et al.*, 2009, 867). These feedbacks highlight the synergies and uncertainties that are inherent in trying to establish the best AQM intervention to implement. Thus, when selecting an intervention to meet air quality targets, there need to be criteria in place to ensure that the impacts on climate change are also considered. Metrics such as global warming potentials (GWPs) could be used to gauge the impact for climate, which could then be weighed against the potential impacts on ambient air quality.

The focus of local action toward reducing NO_x and PM emissions to meet emission standards under the AQA could thus act to support long-term climate cooling effects. In the case of SO_2, especially where mean annual ambient air quality targets are now being met, the impact of further SO_2 reductions for decreasing short-term cooling effects needs to be considered and the trade-offs clearly communicated to encourage action toward reducing climate change pollutants with warming effects.

5.2.2.3 Climate change impacts on air quality

In AQM, emission standards are based on scenarios that will allow for progressive decreases in primary anthropogenic pollutants such as NO_x and PM through the application of air pollution prevention or control measures. It is expected that such emission reductions will contribute to improved ambient air quality to levels that do not compromise human health. However, such predictions of emission reductions are thought to be misleading, as these estimates are typically made on the assumption that the climate will remain constant. It is suggested that future climate change is likely to impact the meteorological factors that influence air quality (Bernard *et al*., 2001; Hedegaard *et al*., 2008), with the potential to increase the severity and duration of air pollution events.

For Durban, projections of climate change show that an increase in the number of hot days can be expected, with the occurrence of consecutive days with temperatures above 30 °C in the summer months of January and February being 5 to 6 times higher, and 12-14 times in March, October and November (Naidoo *et al*., 2006). Changes to temperature have important implications for natural and anthropogenic emissions of primary pollutants and secondary chemical reaction rates. Furthermore, Engelbrecht (2005) indicates that under future climate change scenarios there will be an intensification of the Hadley circulation cell, with important implications for South Africa. This is significant, as intensified high pressure systems are characterised by stable conditions and temperature inversions, reducing air pollution dispersion and increasing the potential for pollutants to stagnate in an area.

Despite the knowledge of the possible impacts of climate change on meteorological factors that are likely to influence air pollution, this has not been taken into consideration in the development of Durban's AQMP. AQM systems in the city do not currently include any linkage to projected future regional meteorology preventing an understanding of whether projected climate change will act to exacerbate air pollution in the area. The AQM systems needs to be expanded to include a longer term vision, where global circulation and regional meteorological models are used to obtain an indication of future large scale and synoptic weather patterns which should then be combined with air quality models. Access to such information would ultimately allow for the AQMP to effectively support local adaptation plans.

5.2.3 Summary of case study

The case study illustrates the opportunities and complexities involved in trying to incorporate climate change concerns into an AQMP. In the short-to medium-term the challenge is to ensure that air quality interventions that do not act to negatively influence GHG emissions are prioritised. In Durban, industrial fossil fuel consumption and road transportation present cross-cutting policy imperatives and the decisions taken to meet these specific challenges may determine the city's success in simultaneously achieving air quality targets and mitigating climate change. Significant co-benefits can therefore result from improved co-ordination of industrial, energy and transport plans. However, existing air quality related legislation has a limited role to play in ensuring that air quality interventions are prioritised to have co-benefits or at least result in minimal increases in GHG emissions. In the long-term, climate change impacts on meteorological factors that influence air quality also need to be considered in the AQMP so that the most effective interventions can be selected to support the city's climate change adaptation and mitigation goals.

5.3. Key recommendations for the inclusion of climate change consideration into local AQMPs

5.3.1 Short-to medium-term climate change concerns in AQMPs

A co-benefits approach to AQM could help to co-ordinate and prioritise different strategies within a city and ensure that the best policies for simultaneously meeting the multiple goals of road safety, use of cleaner fuels, and air pollution reduction are implemented. Furthermore, such an approach may help to bridge the gap between the implementation of climate change and air quality policies, allowing for progress to be made in terms of GHG mitigation in the short-term.

A comprehensive emissions inventory of air pollution and GHG emissions, developed by cities using a nationally consistent approach will provide a platform to guide equitable GHG emission reductions and allow for the identification of opportunities to achieve co-benefits. Scientific knowledge on synergies and trade-offs needs to be translated into policies that will support the adoption of co-beneficial measures. AQMPs need to be designed to take cognisance of impacts for GHG emissions, avoiding increases in GHG emissions.

To achieve this, the major polluting sectors and local authorities tasked with control over them, need to be educated about interventions that have co-benefits. With this approach it is hoped that the realisation of the potential multiple environmental benefits will encourage the voluntary adoption of co-beneficial emission reduction measures, even though it is recognised that there are no financial incentives or disincentives associated with achievement or non-achievement of emission reductions respectively. Such an approach may lack the same support as one based on regulations with resultant financial or other penalties (Rehan and Nedhi, 2005), but it is considered to be a short-term option.

Existing air quality related legislation has a limited role to play in ensuring that interventions with co-benefits are prioritised. In the case of the industrial sector, AELs or municipal by-laws can ultimately be used as the mechanisms to regulate the extent to which industries are required to consider the climate change implications of their air quality interventions.

Opportunities for co-benefits are potentially much larger within the road transport sector. However, the options that a city has to achieve these co-benefits are far more limited, as there is currently no national legislation or policy that regulates VKT. Furthermore, a city acting in isolation can only have a relatively minor influence over atmospheric emissions from road transport. The impacts of inter-city travelling, VKT by local motor vehicles and road freight transport may prevent significant improvements from being made from local fleet renewal campaigns. Furthermore, the average age of motor vehicles in the country is over 10 years old, thus there may be limited environmental benefits to interventions that require changes to fuel specifications and the types of fuels that are used by motor vehicles. In addition, whilst measures such as congestion charging have been shown to be successful in reducing VKT in developed cities, the implementation in South Africa may not be justifiable, and would have to be considered in the light of other socio-economic issues. Regulation of emissions from heavy-duty vehicles used to transport freight through emission standards should therefore be explored.

5.3.2 Long-term climate change concerns in AQMPs

Work by authors such as Nemet *et al*. (2010) suggest whilst a co-benefits approach to achieving GHG emission reductions may help developing countries overcome international collective action problems, it may also act to complicate the implementation of an international climate agreement. Specifically, the concern is that if cities within developing countries achieve GHG emission reductions as part of their air quality policies, it might prevent these countries from actively engaging with GHG emission reductions at an international level, preventing substantial GHG emission reductions from being made. Thus the question becomes, will placing climate change on the same decision-making platform as the air quality agenda detract from specific air quality and climate change goals?

There is no simple answer to this question. Within a South African context, there are potentially numerous advantages to incorporating climate change concerns into AQMPs. Adopting a co-benefits approach to AQMPs may allow for early action on climate change mitigation. It may help South African cities to recognise the value of designing their response to air quality issues in a manner that favours GHG emission reductions. This is especially relevant for cities that lack the financial resources and institutional capacity to effectively implement air quality policies as it may allow for higher levels of pollution abatement through opportunities to participate in the carbon market.

However, in the long-term, a co-benefits approach to AQMPs alone cannot be expected to meet GHG mitigation targets. Policies that require cities to develop GHG emissions action plans should also be promoted. These climate policies should further support interventions with co-benefits for air quality. Thus, in the long-term, a system that integrates projections of the city’s future economic growth with the local government’s AQMP and climate change mitigation goals would highlight the responses needed from industries, and transport and energy departments (Fig. 5.4). The interventions need to be considered within the context of local adaptation to climate change, to ensure that ambient air quality standards will be achieved within a changing climate. As interventions may offer disputed benefits for climate change and air quality due to the complex linkages, interactions and feedbacks that exist (described earlier), the long-term vision for air quality and climate change mitigation in the city together with a risk assessment framework should ultimately guide the selection of an appropriate measure.

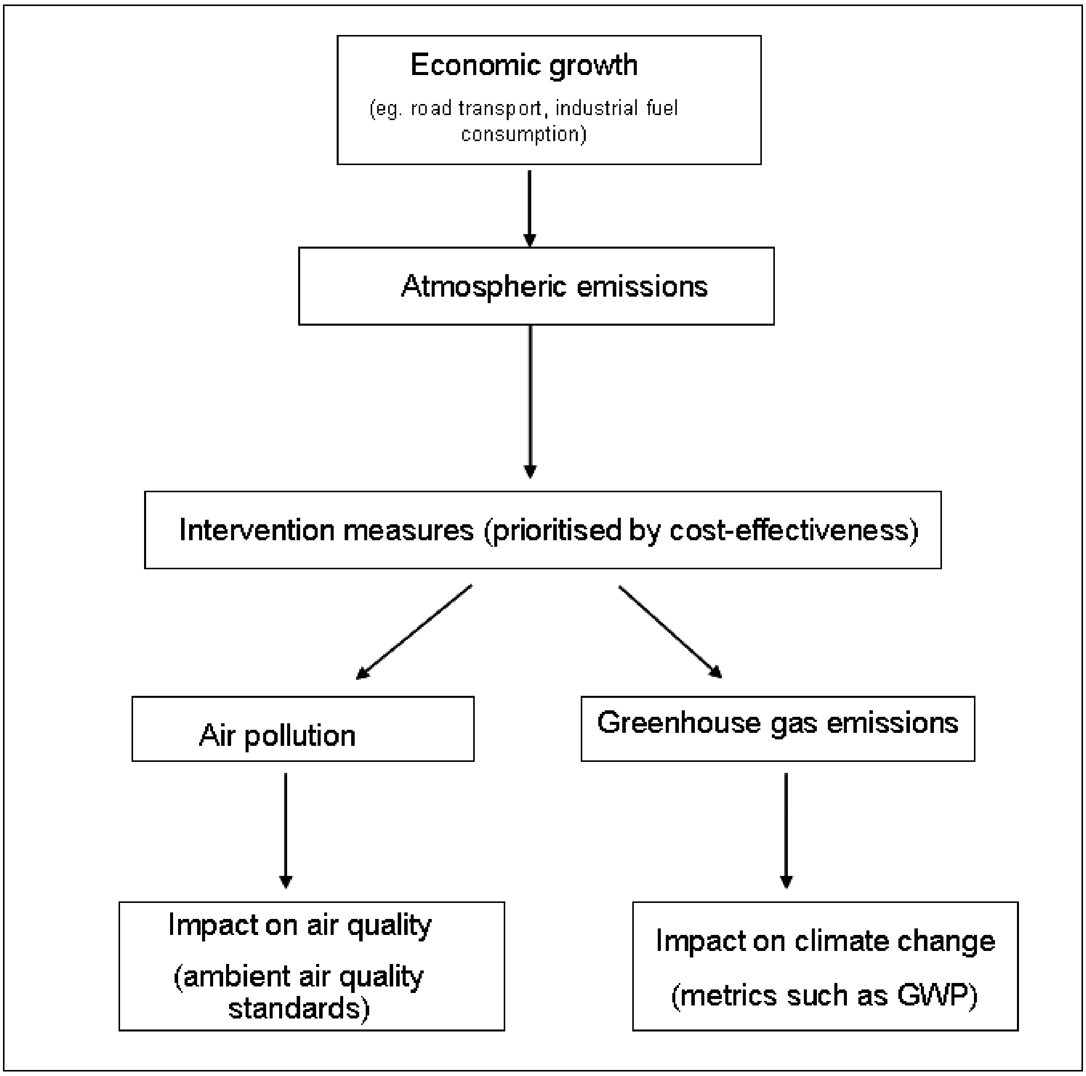

Figure 5.4: Long-term approach to air quality management and GHG mitigation

5.4 Concluding remarks

Local AQMPs present an opportunity for authorities to ensure that air quality policies are used to promote a culture of awareness of the need to reduce GHG emissions and to place climate change issues on the table for decision-makers. Despite the lack of climate change mitigation targets for cities, local AQMPs could still be used to influence the adoption of best practices to at least curb the growth of GHG emissions. Cities that envision themselves as becoming low carbon societies thus need to consider and plan for the role that AQMPs can play in achieving this goal. The challenge that faces policy-makers is to convert the potential for climate change co-benefits from AQMPs into operational policies that best exploit the synergies in light of sustainable development goals, availability of resources, and overcoming any political, technological and financial barriers that exist.

The implementation of policy, education and increased awareness of the opportunities for co-benefits are important steps that have to be taken. Specifically, in the short- to medium-term, climate change mitigation considerations need to be integrated into existing air quality policies and legislation in order to facilitate effective co-management of the issues. Policies or strategies that regulate the implementation of AQM interventions in favour of those with co-benefits for GHG emissions need to be developed. The legislative controls should ideally filter down from the AQA to provincial and local authorities, so that a consistent approach is applied to all related activities and sources of emissions. In this way no particular city or sector is unfairly regulated and the competitiveness between cities is not influenced. However, cities should be allowed to be proactive and develop stricter guidelines and take action to promote a co-benefits approach through municipal by-laws.

In the long-term, a co-benefits approach to AQM cannot be expected to adequately address the linkages between air quality and climate change, as it does not take into account complex atmospheric feedbacks and climate change impacts on air quality. Local AQMPs thus needed to be designed to take cognisance of the long-term adaptation and GHG mitigation objectives of the city. Success in implementing an integrative approach to AQM at a local level could make it more feasible for higher levels of government to adopt similar policies.

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CHAPTER 6:

CONCLUSION

6.1 Introduction

In recent years significant research has focused on understanding the scientific linkages and interactions between air quality and climate change. The improved understanding of the complex atmospheric interactions and the relationship between sources of emissions suggest that the traditional policy responses to these environmental challenges have to be reformulated, requiring a shift toward integrative air quality and climate change policies.

This is especially relevant for developing countries that are still grappling with growing urban air pollution challenges and further typically follow a sequential approach with regard to policy matters, prioritising those with local and more immediate impacts and shifting those, such as climate change, which have longer-term and less visible local impacts to a lower ranking on the priority list. The development of air quality policies that consider climate change issues may help to bridge the gap between the implementation of air quality and climate change mitigation policies in these countries. Opportunities therefore exist for developing country cities to play a role in initiating innovative responses to climate change, with the use of air quality policies being a possible avenue to achieving this.

This study was aimed at using the understanding of the scientific linkages and interactions between air quality and climate change as a basis to explore the opportunities to integrate climate change considerations into local air quality management plans (AQMPs) in South Africa. In this chapter, the key findings of this research are summarised and the implications of this study and recommendations for future air quality management (AQM) and climate change research in the country are discussed.

6.2. Summary of study

This dissertation consists of six chapters.

Chapter 1 introduces the project, provides a rationale for conducting this research and highlights the key aim and objectives of the study.

The first objective of this study was to review the scientific interactions and linkages between climate change and air quality. This was achieved in Chapter 2 which focused on understanding the direct and indirect impacts of air pollution for climate change and the impacts of climatic change on air pollutants. It was found that many air pollutants such as ozone, particulate matter and sulphur dioxide have close links to climate change. In addition to this, it was established that a warmer, evolving climate is likely to have consequences for air quality due to possible impacts on pollution sources and meteorology.

The theoretical knowledge of the scientific linkages and interactions for climate change and air quality provides the basis to explore policy implications for South Africa. Air quality legislation in the country, namely, the National Environmental Management: Air Quality Act (*Act No.39 of 2004)* (the AQA) states the importance of air quality processes taking cognisance of impacts for climate change, although there is no guidance on how this can be achieved. It is argued in Chapter 2 that the generic framework for the development of local AQMPs can accommodate the inclusion of climate change concerns.

The second objective of the study was to make recommendations for the inclusion of emission control measures that produce co-benefits for local air quality and GHG mitigation through a case study of the city of Durban. This objective was met in Chapters 3 and 4 where the opportunities for co-benefits, that is, the simultaneous reduction of air quality and GHG emissions within the road transport and industrial sectors were explored. These sectors are important contributors to the city's GDP and are also significant contributors to air pollution and GHG emissions. The challenge that the city faces is to be able to reap the socio-economic benefits that these services offer, whilst minimising the environmental and health impacts. Interventions that target energy efficiency and reduce fossil fuel consumption within these sectors have the potential for achieving multiple social and environmental benefits.

The third objective of the study was to use the case study of Durban to develop recommendations for the integration of climate change considerations into local AQM plans in South Africa. This was achieved in Chapter 5, in which the policy interventions that may support these co-beneficial interventions were explored. It was found that existing air quality related legislation has a limited role to play in ensuring that air quality interventions are prioritised to have co-benefits or at least result in minimal GHG emissions. Within the industrial sector, atmospheric emission licenses (AELs) are being issued to industries that fall within the listed activities published under the AQA and are used to regulate the release of harmful air pollutants. However, the impact of air quality interventions for GHG emissions is not currently a condition in AELs. In the case of the road transport sector, the opportunities for co-benefits are potentially much larger, however there may be difficulty in achieving them. The impact of national emission standards for motor vehicles for example, is limited due to the age of the motor vehicles in the fleet and further does not influence the vehicle kilometres travelled (VKT).

Specific direction from government authorities is therefore required to facilitate the adoption of best practice in AQM to ensure that all the stakeholders that contribute toward maintaining acceptable ambient air quality recognise the implications of their actions for GHG mitigation. An important first step in this process is the development of air pollution and GHG emissions inventories to guide the conceptualisation of the opportunities for co-benefits. The introduction of voluntary programmes, municipal by-laws and or regulatory guidance from the AQA, that support strategies with co-benefits is critical to ensure that local AQMPs can be used in the short- to medium-term to promote reductions or avoidance of GHG emissions. In the long-term, a co-benefits approach to AQMPs alone cannot be expected to meet GHG mitigation targets. Policies that require local governments to develop GHG emissions action plans should also be promoted. These climate policies should further support interventions with co-benefits for air quality and long-term AQM planning should consider the possible impacts of climatic changes on meteorology and sources of emissions.

6.3 Recommendations for future work

From this study it is evident that further research is needed to inform the long-term role that local AQMPs can play in GHG mitigation and support of local adaptation measures. Specifically, there is a need to determine the impacts of proposed climate change mitigation strategies for air pollution, to improve the country's ability to report on GHG emissions and to enhance the understanding of the possible impacts of climate change on air quality. The leveraging of this information by local authorities is needed to fully capture and best exploit the complex linkages that exist. This is imperative to ensure that the most appropriate interventions are identified, implemented and used toward meeting the objective of creating low carbon, resilient cities.

6.3.1 Research needs

6.3.1.1 GHG mitigation co-benefits for air quality

From the discussions of the previous sections it is clear that the short- to medium-term options for reducing air pollutants have trade-offs and synergies for GHG emissions. The reduced use or more effective use of fossil fuel resources presents the most obvious opportunity for co-benefits, whilst the technological options for reducing emissions offer mostly trade-offs. The imminent climate change mitigation policy in the country offers the potential to reap substantial benefits for air quality.

Specifically, South Africa has made voluntary commitments to reduce GHG emissions by 34% by 2010, contingent on international funding, technology transfer, and a globally binding agreement. To achieve this goal for GHG mitigation, the government is likely to promote economic instruments, behavioural change and the use of carbon-friendly technologies and fuels, as recommended by the country's study on long-term mitigation scenarios for climate change. The implementation of these measures is likely to have simultaneous implications for air quality which have not been quantified or considered.

For instance, the introduction of a carbon tax in South Africa is widely recognised as one of the possible economic instruments to reduce carbon dioxide (CO_2) emissions. However, the enactment of such a tax must be accompanied by holistic restrictions and guidance on the methods by which the GHG emissions reduction is to be brought about. For example, in the case of carbon capture and storage technologies on new coal-fired power plants to reduce CO_2 emissions, the possibilities of an increase in air quality pollutants needs to be considered and as such the appropriate air pollution abatement plans must be implemented simultaneously.

However, other measures such as the introduction of more stringent fuel efficiency requirements to stem the increase of GHG emissions from the transportation sector and the incentivising of renewable energy sources in industries could have significant potential for co-benefits for air quality. These measures need to be assessed for the role that they could possibly play toward promoting air quality improvements, especially within priority areas for AQM identified through the AQA. Integrating air pollution abatement and climate change mitigation policies could yield potentially large cost reductions compared to treating those policies in isolation. Policy-makers thus also need to be mindful of this, recognising the opportunities for financial savings from using climate change policy to promote air quality improvements.

6.3.1.2. Reporting on GHG emissions

Irrespective of the whether a local government is looking to assess the opportunity for co-benefits from an AQMP or from climate change mitigation, an important factor in both of these approaches is for decision-makers to have access to reliable estimates of GHG emissions. South Africa’s GHG emissions inventory is out-dated, developed for the year 2000 as part of its second communication on climate change to the United Nations Framework Convention on Climate Change (UNFCCC). As a non-annex 1 country, a low level of detail on the emissions inventory was required at a tier 1 level. This emissions inventory is currently being updated for the year 2009.

In addition, only 10 cities have compiled GHG inventories. Presently, there are no South African guidelines on how local authorities should proceed with the development of GHG emissions inventories. As such those that have been developed were based on international methodologies, specifically that developed by ICLEI (Local Governments for Sustainability). Whilst such guidelines prescribe the processes to ensure adherence to good practices when estimating and reporting on GHG emissions they may not necessarily capture the inherent complexities of South African cities, particularly those related to the life cycle of goods used, industrial processes and road transportation. Furthermore, currently there is no external review process in place to determine how representative these inventories are. An important directive for the national government is to provide a standard methodology to guide the development and review of GHG emissions inventories at a local government level.

Furthermore, the key polluting sectors need to be encouraged to improve their ability to report on GHG emissions. For example, the contribution of industrial processes (non-energy) to GHG emissions may be poorly understood and is not quantified by all industries. This represents an important source of emissions that requires reliable estimates to be made. The capacity of industries to report adequately on GHG emissions thus also needs to be developed.

GHG emissions inventories developed using a consistent approach will provide a platform to guide equitable emission reductions. Specifically, GHG emissions estimates of a high confidence level alongside a conventional air pollution inventory will be vital in facilitating a thorough conceptualisation of key sources of emissions. It will further through scenario testing allow for an assessment of the potential contribution that a co-benefits approach can make towards simultaneously achieving AQM goals and local targets for GHG mitigation.

6.3.1.3 Development of an improved understanding of air quality and climate change atmospheric interactions within a South African context

The characterisation of the effects of climate change on air quality is necessary in order for air quality policy planners to determine if the assumption of a constant climate in air pollution reduction strategies is in fact valid. In order to determine the effects of climate change on air quality, both air quality and climate models have to be linked. The linkage of climate and air quality models is often described as complex due to the difference in resolutions of these models and also due to factors such as the long simulation times required for the assessment of climate-air interactions. In order to simulate the relationship between global and regional meteorology, and air quality, a modelling system that integrates global climate, regional climate and air quality models has to be developed.

AQM systems in South Africa do not currently include any linkage to projected future regional meteorology. There is an urgent need to address the knowledge gap that this presents and is an area that requires significant investment in research. Future research needs to focus on the design of an integrated modelling framework to investigate the impact of climate change on air quality in South Africa. This integrated modelling framework should have the capability of providing regional projections of climate and air quality under alternative global change scenarios.

6.3.2 Building local capacity in AQM and climate change

Local governments and decision makers within the key polluting sectors need to be equipped with the capacity to adequately recognise and thus be positioned to harvest the opportunities to include climate change considerations into their AQM decisions. Capacity building, education, support and training on air quality and climate change issues is therefore needed.

Local governments that develop AQMPs are expected to establish the capacity to collect and maintain air pollution emission databases. Additional training of air quality officials in support of instituting programmes to estimate GHG emissions and perform assessments of co-benefits is needed. Established environmental and other legislation in South Africa ensures that local governments are well capacitated with authority over waste-management, land-use and transport planning. Local governments therefore have authority over the sectors that are most likely to be impacted on by climatic change and are importantly the sectors that make considerable contributions to GHG emissions. Thus, in addition to AQMPs, there are various other strategies and policies that are aimed at ensuring that the city functions efficiently. However, these plans are often not well co-ordinated, with different time-frames to expected outcomes and solutions that are based on the individual sector's objectives. Opportunities to optimally capture synergies between these plans and reduce trade-offs especially in light of climate change mitigation, for which there is currently no specific plan in place, could thus be overlooked.

There is a need to harvest the potential for co-benefits within these sectors, and as such the AQMP should serve as a platform to educate different local government departments on the potential for their actions to support the objectives of the AQMP and opportunities for co-benefits for climate change mitigation and vice versa. Thus the provision of support on co-benefit analysis and raising awareness of the issues by disseminating information are important additions that should be included during the implementation of an AQMP. This should ultimately enhance the capacity of local authorities to deal with climate change and air quality issues through improved co-ordination of different policies and strategies.