A review of scientific linkages and interactions between climate change and air quality, with implications for air quality management in South Africa

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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. 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.

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. Furthermore, many of the processes that play a role in the chemical composition of the atmosphere are subject to alterations due to climate change[1] and thus may impact on air quality.

This paper 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 paper 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.

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 greenhouse gas 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.

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.[2]

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.[3] Specifically, anthropogenic emissions of precursor gases have contributed to an increase of about 120% in tropospheric O_3 production since pre-industrial times.[4] Elevated levels of tropospheric O_3 are a concern, as O_3 affects human health and vegetation. Tropospheric O_3 is also the greenhouse gas with the third largest radiative forcing, thus contributing to the greenhouse effect and climate change.[5,6,7]

Future levels of tropospheric O_3 are likely to be impacted on significantly by climate change. Studies such as those by Hogrefe et al.[8] and Bell et al.[9] have modelled the response of tropospheric O_3 to possible alterations in climate for the United States of America (USA), predicting O_3 increases. Langner et al.[10] also noted that climate change could result in increases in near-surface O_3 levels (above 40 ng/g) over southern and central Europe. The impact of climate change on the chemical and transport processes that influence tropospheric O_3 is discussed below.

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.[7,11]

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.[12] Studies that have modelled future O_3 concentrations have found that an increase in temperature of 2 °C leads to an increase of 2% – 4% in near-surface O_3 levels, and that an increase of 5 °C results in a 5% – 10% increase in O_3 levels.[5] Dawson et al.[13] 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).[13] 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 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.[14]

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[15] through the following reactions:

$$O_3 + h\nu \rightarrow O(^1D) + O_2 \quad \text{[Eqn 1]}$$

$$O(^1D) + H_2O \rightarrow 2OH \quad \text{[Eqn 2]}$$

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.[16]

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.[17] 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.[16,18] 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.[13]

Cloud cover

The presence of clouds can alter the concentration of O_3 by changing radiation transfer and vertical transport.[19] 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.[20] 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,[5] 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,[13] 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[17] reported that decreases in low-level cloud water in the USA 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.[21] 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.

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).[22,23] The exchange of O_3 between the stratosphere and troposphere is also associated with the large-scale Brewer–Dobson circulation system.[24]

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.[25,26,27] 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.[26] 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.[27]

Convection

Convection is an effective mechanism for removing pollutants from the lower troposphere to the middle and upper troposphere.[25] 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.[28] Convection also allows for the vertical mixing of O_3 precursors, which are transported to the middle and upper troposphere.[28] Furthermore, deep convection has the potential to generate lightning flashes, which result in the production of large amounts of NO in the free troposphere.[25]

It is expected that, as the climate warms, convection will intensify in most parts of the world, with the probable exception of the tropics.[7] 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

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of NO_x into the upper troposphere, where there is greater O_3 production efficiency.[7] 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[29] (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.[13] This relationship is also true for O_3,[11] 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).[14] However, Holzer and Boer[30] 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.

Tropospheric O_3 precursor gases

CH_4

Since the middle of the 19th century, levels of CH_4 have increased rapidly due to industrialisation and increased agricultural production.[31] 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.[31] CH_4 production is influenced by temperature, with maximum production occurring at temperatures ranging from 37 °C to 45 °C.[32]

CH_4 is the greenhouse gas 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.[33] 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.[34] 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.[6,34]

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.[4] 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.[33] 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.[33]

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 emissions.[16] This has implications for O_3, as reduced CH_4 means reduced background O_3 levels.[16] 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%.[32]

NMVOCs

Isoprene and monoterpene represent two of the most important NMVOCs involved in tropospheric O_3 chemistry.[35,36,37] These natural emissions occur in order to protect plants from abiotic and biotic stresses, and to attract pollinators.[38] 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.[39] 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,[40] with higher temperatures generally resulting in higher emissions.[41,42]

Studies in the USA have shown that regions expected to have warmer summertime temperatures could experience a 50% to 60% increase in isoprene emissions.[18] The impact of increasing isoprene on O_3 levels was also assessed by Zeng et al.,[43] 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 ng/g – 6 ng/g were noted. Meleux et al.[44] 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.

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.[45,46] In tropical regions, the main source of NO_x is human-induced biomass burning,[47] whereas in the Northern Hemisphere 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.[45]

$$NO + O_3 \rightarrow NO_2 + O_2 \quad \text{[Eqn 3]}$$

Estimates of the magnitude of biogenic emissions of NO compared to anthropogenic sources remain uncertain due to the lack of data,[48] although it is estimated that tropical soils account for about 70% of global soil emissions[47] 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, [48] 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 – 12 km altitude range of the atmosphere.[49] 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.[50,51] 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.[7] Murazaki and Hess[17] predicted a significant increase in NO_x emissions over the USA 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.[49] 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.[18]

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.,[5] 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.

Particulate matter

Particulate matter (PM) is also widely acknowledged to have significant effects on air quality and human health,[52] 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.[53] 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} [54] and is known to absorb solar radiation.[55] Sulphate aerosols, which form an important component of $PM_{2.5}$,[56] occur mainly as a result of the oxidation of SO_2 [57,58] and contribute to the cooling of the earth by reflecting sunlight back into space, thus preventing the sunlight from reaching the earth's surface.[59,60]

In addition to their radiative properties, sulphate aerosols indirectly affect climate by inducing changes in clouds. They act as cloud condensation nuclei, altering the cloud-droplet size distribution.[61,62] 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,[63,64] 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.[65] Ramanathan and Feng[65] noted that a rapid reduction in SO_2 emissions without corresponding reductions in black carbon and greenhouse gases 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.[66] However, according to Jacob and Winner,[67] 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.[67] 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 $PM_{2.5}$.[68,69,70] 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.

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 greenhouse gases as a means of preventing what the United Nations Framework Convention on Climate Change deemed dangerous anthropogenic interference in the climate system.[71] Ratified by 183 countries,[72] the Kyoto Protocol prescribes emission reductions, covering a set of six greenhouse gases, namely CO_2, CH_4, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, for the period 2008–2012.[73] 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.[74] 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.[75]

Air quality policies also reveal inadequacies in addressing climate change issues. Firstly, AQM processes generally do not consider greenhouse gas 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 greenhouse gas emissions.[76]

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,[9,77,78] 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.

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 greenhouse gas emitters, contributing 1% of total CO_2 (eq) in 2004.[79] 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,[80] 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[81] 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

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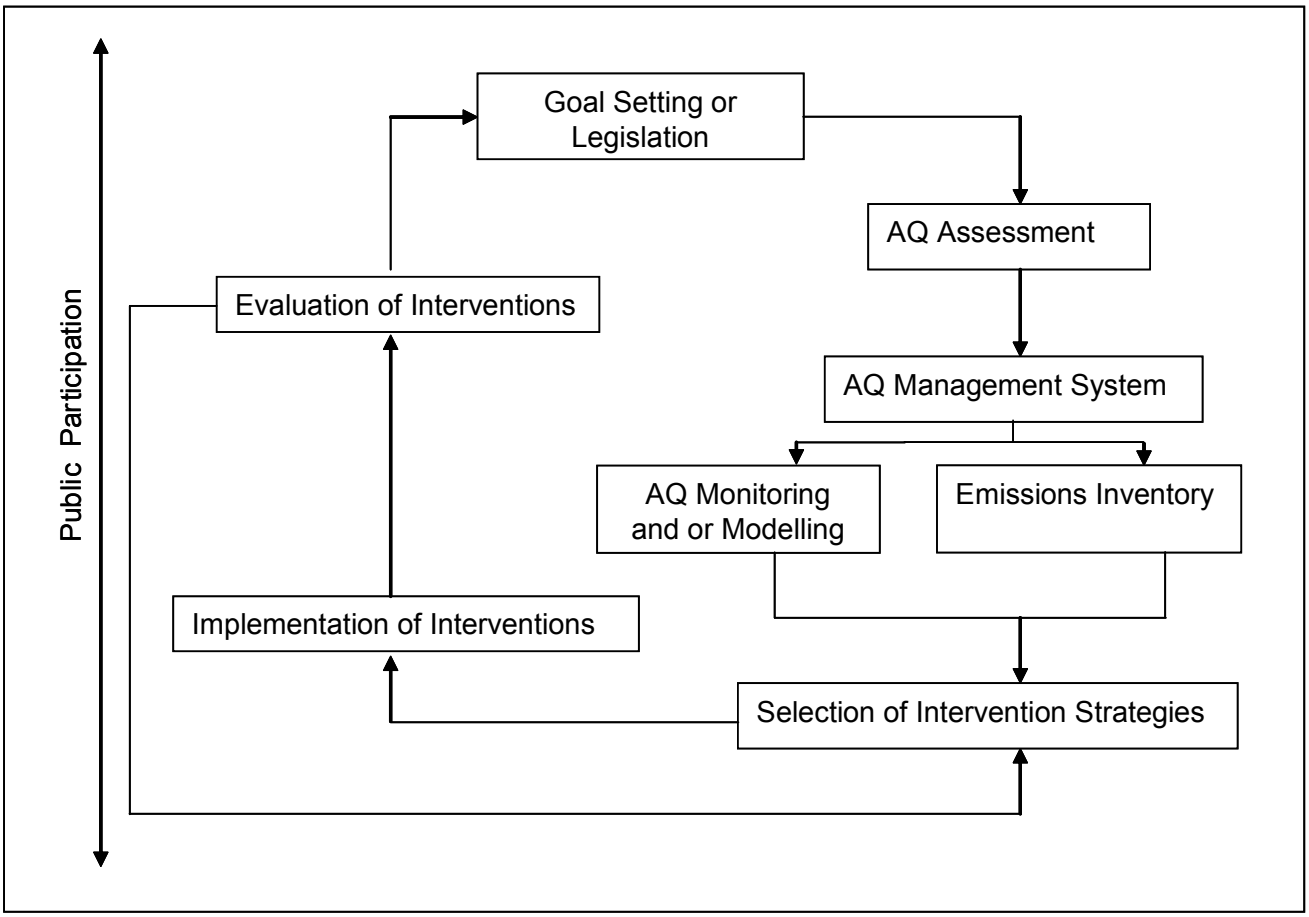

Source: adapted from DEAT[81,82]

FIGURE 1
Process to be followed during the development of an AQMP

the development of South Africa's National Framework for Air Quality Management in 2007,[81] 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 greenhouse gas 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 1 shows the six main steps that guide the development and implementation AQMPs in South Africa.[81,82] 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.

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 greenhouse gases 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 greenhouse gas 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. Firstly, information on greenhouse gas emissions can be included in the baseline assessment and AQM system of AQMPs. The inclusion of greenhouse gas 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 greenhouse gas 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.

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.

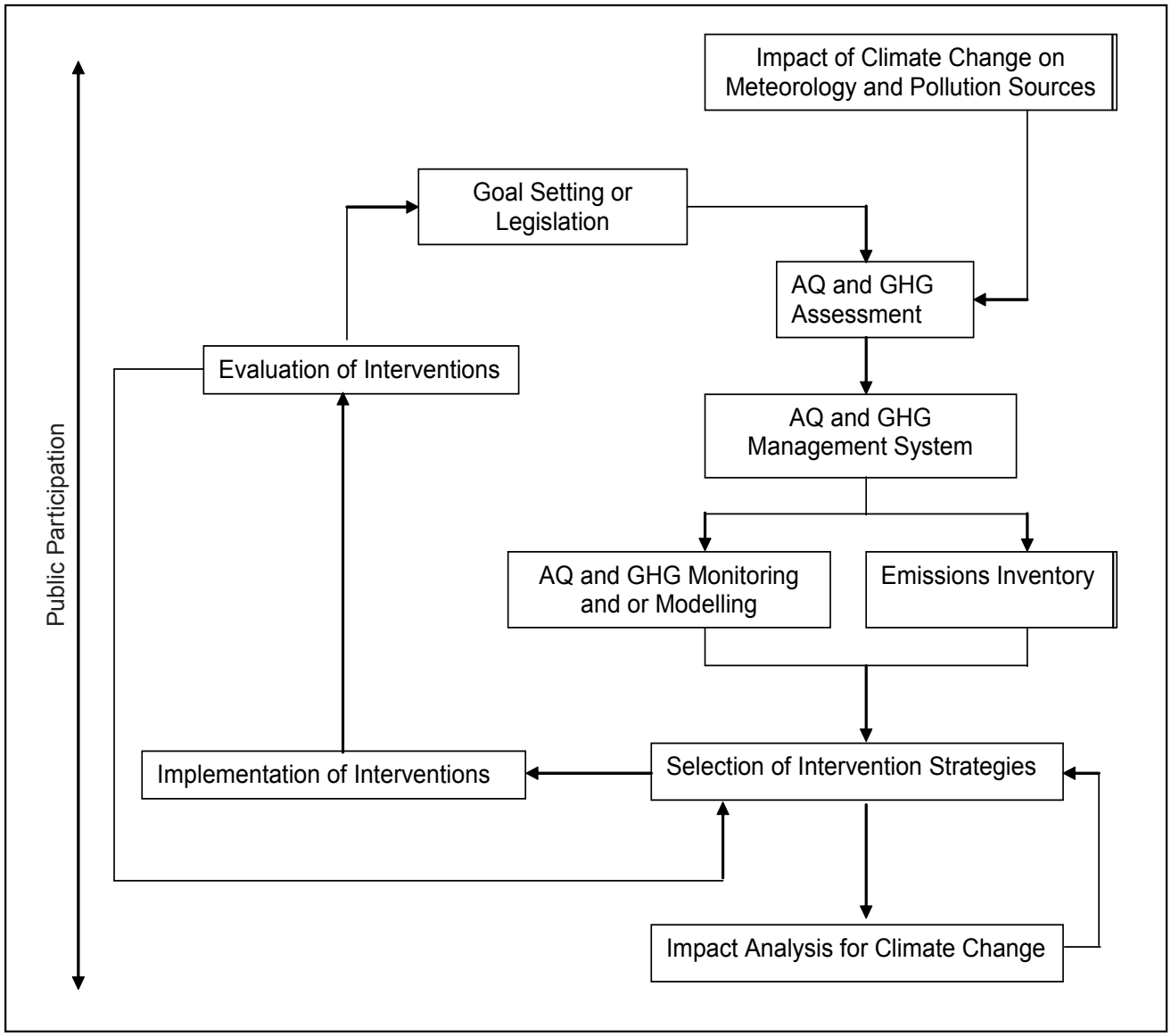

FIGURE 2
Integrative process to be followed during the development of an AQMP

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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