Low Cost Solutions to Achieve Better Air Quality in Sub-Saharan African Cities

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Contents

Abbreviations and Acronyms

ABC	Atmospheric Brown Cloud
ACS	American Cancer Society
AQM	Air quality management
AQI	Air Quality Index
ATD	Arizona test dust
BAQ	Better air quality
BS	Black smoke
CAIPs	Clean Air Implementation Plans
CAI-SSA	Clean Air Initiative for Sub-Saharan Africa
CALMET	CALifornia METeorological model
CALPUFF	CALifornia PUFF dispersion model
CH_4	Methane
CERs	Certified Emission Reductions
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CSIR	Council for Scientific and Industrial Research
CREP	Corporate Responsibility for Environmental Protection
CTM	Chemical transport model
DALY	Disability Adjusted Life Year
DQOs	Data quality objectives
EB	Executive Board
EBD	Environmental burden of disease
ECA	Emission Control Areas
EIA	Energy Information Adminstration
EIA	Environmental Impact Assessment
GAPF	Global Atmospheric Pollution Forum
GHG	Greenhouse gases
GNI	Grand national income
HABITAT	United Nations Settlement Programme
HAPs	Hazardous air pollutants
HC	Hydrocarbons
HCl	Hydrogen chloride
HEI	Health Effects Institue
HFC	Hydroflurocarbons
Hg	Mercury
I&M	Inspection and maintenance
IAEA	International Atomic Energy Agency
LDC	Less developed countries
LPG	Liquid petroleum gas
NMT	Non-motorized transport
NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
O_3	Ozone
OECD	Organization for Economic Cooperation and Development
PAHs	Polycyclic aromatic hydrocarbons
PC	Personal computer
PCBs	Polychlorinated biphenyls
PFCs	Perflurocarbons
PM	Particulate matter
POPs	Persistent organic pollutants

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QA/QC	Quality assurance/quality control
REA	Rapid Epidemiological Assessment
REIA	Rapid Environmental Impact Assessment
SADC	Southern Africa Development Community
SEI	Stockholm Environment Institute
SF6	Sulphur hexafluoride
SIM-AIR	Simple integrated model for better air quality
SO_2	Sulphur dioxide
SSA	Sub-Saharan Africa
SWM	Solid waste management
TAPM	The air pollution model
TEAM	Total exposure assessment methodology
TSP	Total suspended particulate
UF	Ultrafine
UK	United Kingdom
UAM-V	Urban airshed model variable grid
UV	Ultraviolet
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency
VOCs	Volatile organic compounds
YLD	Years lived with a disability
YLL	Years of life lost
WHO	World Health Organization
WMO	World Meteorological Organization
WSSD	World Summit on Sustainable Development

Executive Summary

1. Air pollution in Sub-Saharan Africa (SSA) appears to be on the rise with respect to many key pollutants. In some SSA cities, where monitoring has been performed, levels of urban air pollution exceed World Health Organization (WHO) recommended guidelines. The main cause of urban air pollution is the use of fossil fuels in transport, power generation, industry and the domestic sector. In addition, the burning of firewood, agricultural and animal waste also contributes to pollution levels. Pollutant emissions have direct and indirect effects (e.g. acidification, eutrophication, ground-level ozone and stratospheric ozone depletion) with a wide range of impacts on human health, ecosystems, agriculture and materials.

2. Traditional air pollutants comprise nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), particulate matter (PM), ozone (O_3) and lead. Hazardous air pollutants (HAPs) consist of chemical, physical and biological agents. HAPs are present in the atmosphere in much smaller concentrations and are often more localised, but are toxic or hazardous in nature. HAPs include a range of hydrocarbons (e.g. benzene, toluene and xylenes,) and other toxic organic pollutants (e.g. polycyclic aromatic hydrocarbons (PAHs), pesticides and polychlorinated biphenyls (PCBs))

3. Urban outdoor air pollution is responsible for an estimated 63,000 premature deaths each year in Africa. Indoor use of solid fuels is responsible for 7.5 times this value. Air pollution, outdoor and indoor, affects the health and life chances of millions of people in SSA every day. There is a link between air pollution and poverty since poor people are exposed to higher concentrations of air pollutants and tend to suffer disproportionately from the effects of deteriorating air quality.

4. Figure 1 shows the rapid urbanization being experienced in many parts of SSA (see Annex 1 for a definition of the SSA regions). Rapid urbanization means an increase in motorization and economic activity which in turn leads to increased air pollution if counter measures are not taken. In addition to water and solid waste problems, SSA is facing substantial challenges in terms of urban air quality. These challenges include polluting old vehicles, lack of proper vehicle maintenance and cleaner fuels, a poor regulatory vehicle emission framework and poor enforcement of laws and regulations when they exist.

5. An assessment of urban air pollution in 27 SSA countries identified the key challenges in achieving better air quality in SSA cities. The assessment showed the challenges to managing air quality range from a lack of government commitment and stakeholder participation, weaknesses in policies, standards and regulations, through to deficiencies in data on emissions, air quality and impacts on human health and the environment.

6. There is a growing need in SSA to determine the state of urban air quality and overcome the challenges to improving air quality. This involves identifying the most effective measures to protect human health and the environment. The issue of urban air quality was the subject of a regional conference, Better Air Quality in Sub-Saharan African Cities (BAQ-Africa 2006) held in Nairobi, Kenya in June 2006.

7. The conference recognised the importance of achieving better air quality in SSA cities and identified the need for policy makers to spearhead better air quality management (AQM) in the context of economic development. There is a need to develop legal and regulatory frameworks to achieve better air quality in SSA. This requires mainstreaming AQM in poverty reduction and growth strategies and taking a regional approach to address transboundary air pollution. .

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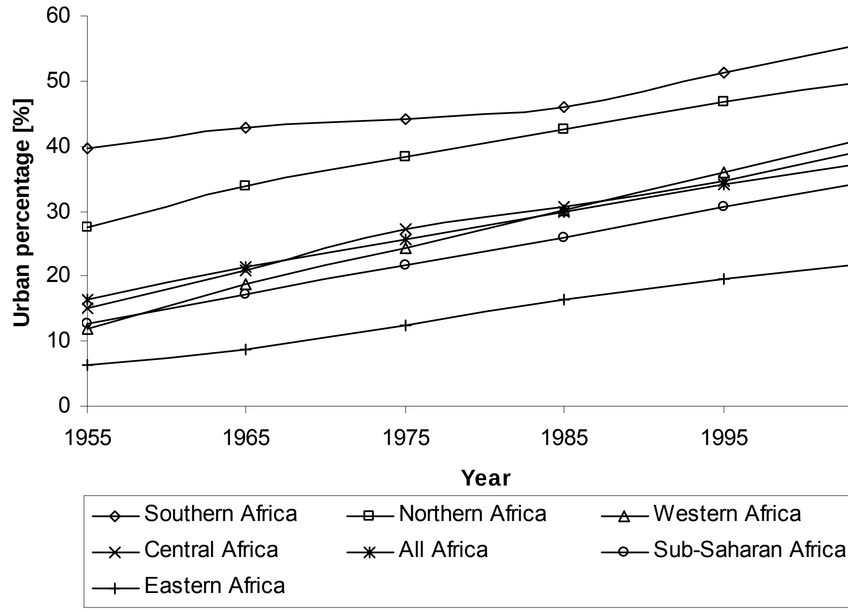


Figure 1: Percentage of urban population in various Sub-Saharan Africa regions

9. AQM aims to maintain and/or achieve a level of air quality which protects human health and the environment. Improvement of deteriorated air quality is necessary to enable further growth of developing countries as air pollution impacts heavily on human health and the environment resulting in high financial costs. Many countries which have developed an effective AQM approach have discovered that the benefits received from emission reductions are usually much higher than the cost of implementing emission reduction measures.

10. An effective AQM strategy is dependent on a number of factors. These include emission inventories, air quality monitoring networks, air quality prediction models, exposure and damage assessments, as well as health and environment-based standards. Along with these factors are a range of cost-effective pollution control measures and the legislative powers and resources to implement and enforce them. These include focussing only on key air pollutants and the application of rapid AQM procedures

11. An important part of AQM is the setting of air quality standards (AQS) and associated exposure times. This is facilitated by using WHO air quality guidelines. WHO has derived air quality guideline (AQG) values and exposure times for approximately 50 non-carcinogenic compounds and unit risk (UR) values for approximately 30 carcinogenic pollutants (WHO, 2000). AQG values for SO_2, O_3 and PM have been recently updated (WHO, 2005). For non-carcinogens AQG values reflect a low risk of incidence of adverse health effects if the AQG values are complied with. If the AQG values are exceeded this does not necessarily mean that adverse effects occur in a population but only that the risk for such effects increases.

12. Setting AQS on the basis of WHO AQG values does not mean that adopted AQS have exactly the same WHO AQG values. Rather AQS have to be set taking into consideration the prevailing exposure levels as well as the environmental, socio-cultural and economic conditions in a country. WHO's AQG values, therefore, should

be considered as target values, only to be implemented stepwise. For PM the WHO has developed a procedure of setting intermediate AQS values which can be implemented in a medium- to long-term process (WHO, 2005).

13. Due to limited availability of financial and human resources and data on air pollution in many SSA countries, it is necessary for solutions to be identified which can be implemented within the SSA context. Because of limited financial resources, SSA countries should focus on selected key pollutants and sources. Thus AQM strategies in SSA may be quite different from those adopted in richer countries. In this Handbook an attempt has been made to identify low cost tools and policy instruments to achieve better air quality in SSA cities.

14. Low cost is defined as placing a low demand on financial, human and data resources. The tools examined in this Handbook include simple rapid assessment techniques to gain an understanding of the type and concentration of air emissions and its impact on human health and environment. As well as a range of policy instruments which, if implemented and enforced, could achieve a relatively quick reduction in polluting air emissions. These tools and measures should form part of an integrated AQM strategy which should be formulated in cooperation with national, regional and local authorities and the different groups of stakeholders that contribute to the problem.

15. This Handbook builds upon the United Nations Environment Programme (UNEP) and United Nations Human Settlements Programme's (UN-HABITAT) *Urban Air Quality Management Toolbook* and the *Toolkit for urban air quality management* (UNEP, 2005) and the *Sustainable Transport Sourcebook for Policy makers in Developing Cities* (GTZ, 2002)

16. The Handbook is aimed at stakeholders and advisors to policy makers in SSA. It provides a strategic set of priority measures and actions (e.g. policy instruments, low sophistication technologies) which can be easily implemented at the country and regional level. Table 1 provides a summary of the low cost tools and policy instruments for AQM in SSA discussed in this Handbook.

17. The Handbook consists of nine chapters including this introduction. Chapter 2 discusses the key feature of an AQM framework. Chapters 3-6 examine the features of emissions, modelling, monitoring and health and environmental assessment. For each component low cost tools are identified. Chapter 7 reviews the policy instruments available to achieve better air quality in SSA cities. It highlights the low cost policy instruments than can be taken to reduce polluting air emissions from industrial, transport and area sources. It also examines the actions available to address transboundary air pollution and climate change.

Table 1: Summary of low cost tools and policy instruments for air quality management in Sub-Saharan African Countries

Component	Objective	Low Cost Option	Description	Examples
Emissions	The objective for emission reduction is to include and/or strengthen enforceable, affordable, sustainable and highly effective measures to assess and reduce emissions. These include: • short-term strategies to reduce emissions to adequately address the overall problem; • use of end-of-pipe and best available control technology solutions to prevent pollution; and • effective measures to reduce air pollution which are fully coordinated with other measures.	Rapid Emission Inventories	An emissions inventory is generally defined as a comprehensive listing of sources and an estimation of the magnitude of air pollutant emissions in a geographic area during a specific time period. Rapid Emission Inventories provide a simplified and user-friendly framework for emissions inventory preparation. Rapid Emission Inventories are suitable for use in different developing and rapidly industrialising countries and are compatible with other major international emissions inventory initiatives.	Global Atmospheric Pollution Forum's rapid emission inventory manual and EXCEL workbook. World Health Organization's Rapid Inventory Assessment System (RIAS) and Decision Support System for Industrial Pollution Control. The International Sustainable Systems Research Center's International Vehicle Emissions (IVE) Model, which focuses on control strategies and transportation.

Table 1: Summary of low cost tools and policy instruments for air quality management in Sub-Saharan African Countries (cont/)

Component	Objective	Low Cost Option	Description	Examples
Modelling	The objective for air quality modelling is to support and strengthen national and local air quality estimates and allow source apportionment and estimations of transboundary pollution. This includes quality assured emission data; regional harmonisation of dispersion models and quality assured topographical and meteorological input data for more advanced models.	Simple Dispersion Models	A dispersion model estimates concentration levels at any point in space and, depending on the availability of meteorological information, for any time. Box models illustrate the simplest kind of material balance. To estimate the concentration in a city, air pollution in a rectangular box is considered under the major simplifying assumptions. A Gaussian dispersion model is normally used for considering a point source such as a factory smoke stack. It attempts to compute the downwind concentration resulting from the point source. An airshed model, rather than tracking the plumes of contaminants from point, line and area sources, divides the whole area into a grid of cells, and models what happens as contaminants are moved by the wind from one cell to the next. Airshed models can also take account of chemical transformations that occur in the atmosphere.	The USEPA´s AERMOD Modelling System uses a Gaussian dispersion model. More advanced dispersion and airshed models require more detailed emission data in order to give a precise and representative estimate for the area under consideration. More advanced models currently available include: The Air Pollution Model (TAPM) CALPUFF (Puff model) Urban Airshed Model variable grid (UAM-V) CALGRID Models III photochemical-aerosol modelling system.

Table 1: Summary of low cost tools and policy instruments for air quality management in Sub-Saharan African Countries (cont/)

Component	Objective	Low Cost Option	Description	Examples
Modelling	The objective for air quality modelling is to support and strengthen national and local air quality estimates and allow source apportionment and estimations of transboundary pollution. This includes quality assured emission data; regional harmonisation of dispersion models and quality assured topographical and meteorological input data for more advanced models.	Source Apportionment	Source apportionment (SA) is the determination of the contribution (fraction, percentage or portion) of air pollution sources at a location of interest. A source-oriented approach to SA starts from an emissions inventory and uses dispersion models in the form of chemical transport models (CTMs) to estimate the contribution of each source at a receptor location. A receptor-oriented approach to SA uses mathematical or statistical procedures to compare the profiles of gases and particles (chemical and physical characteristics) at sources and receptors in a given area to estimate the presence and fraction of source contributions at receptor locations.	Comprehensive Air quality Model with eXtension (CAMx) is a publicly available model for integrated assessment of gaseous and particulate air pollution.

Table 1: Summary of low cost tools and policy instruments for air quality management in Sub-Saharan African Countries (cont/)

Component	Objective	Low Cost Option	Description	Examples
Monitoring	The objective for monitoring air pollutants is to establish and/or strengthen national and local air quality monitoring programmes. These include: Representative coverage of outdoor air quality monitoring systems; Periodic review of air quality monitoring issues; Production of baseline data; Satisfactory maintenance of monitoring systems and procuring spare parts; Obtaining data of known quality and their wide dissemination; Focus on quality control and quality assurance of monitoring programmes; Close collaboration among different monitoring agencies; Use of standard operating procedures for monitoring, for data analysis and presentation;	Rapid Air Quality Monitoring Techniques	Major air quality monitoring methods exist include: Passive/diffusive sampling: a sample integrated over exposure time is collected without the use of power supply. Active sampling: a sample integrated over exposure time is collected by pumping the pollutant to the sampler. Automated monitoring: the sample is analysed on-line and in real-time.	Passive/diffuse samplers include the tube and badge type samplers mainly used for the detection of sulphur oxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3) and carbon monoxide (CO). The Radiello Diffusive Sampling System used to measure O_3, NO_2, SO_2, volatile organic compounds (VOC's), hydrogen fluoride (HF), hydrogen chloride (HCl), benzene-toluene-xylenes (BTX), and aldehydes. The High Volume Sampler is an active sampling device for total suspended particulate (TSP) and particulate matter (PM_{10}).

Table 1: Summary of low cost tools and policy instruments for air quality management in Sub-Saharan African Countries (cont/)

Component	Objective	Low Cost Option	Description	Examples
Monitoring	Harmonisation of monitoring networks and devices; Monitoring of transboundary air pollution; Monitoring of air quality in urban and peri-urban areas; and Hotspot monitoring.	Rapid Air Quality Monitoring Techniques		The MiniVol Portable Air Sampler is an automated monitoring device that samples ambient air for PM (TSP, PM_{10}, $PM_{2.5}$) and/or non-reactive gases (CO, NO_x) simultaneously. The DustTRAK™ Aerosol Monitor is a portable, automated (i.e. battery-operated) laser photometer with real-time mass concentration readout and data logging capability. The monitor provides reliable exposure assessment by measuring particle concentrations corresponding to respirable size ($PM_{4.0}$), PM_{10}, $PM_{2.5}$ or $PM_{1.0}$ size fractions.

Table 1: Summary of low cost tools and policy instruments for air quality management in Sub-Saharan African Countries (cont/)

Component	Objective	Low Cost Option	Description	Examples
Health and Environmental Assessment	The objective for health and environmental assessment is to establish and/or strengthen national and local programmes which monitor the health and environmental impact of air pollution in a harmonised way. This includes: Undertaking long-term studies of health and environmental impacts due to air pollution; Strengthening institutional capability; Assessing of health, environmental and economic impacts of air quality; Augmenting and disseminating information on health and environmental impacts; Ensuring spatial and time representativity of monitoring sites for actual exposure of humans and the environment.	Rapid Epidemiological Assessment Studies	Rapid epidemiological assessment methods include: Use of the WHO environmental burden of disease approach and applying known exposure-response relationships for air pollution impacts to estimate mortality and morbidity. This approach requires knowledge of exposures (air pollutant concentrations and durations). Use of the SIM/Air model to estimate the health impacts on the basis of modelled emissions, simulated concentrations and known exposure-response relationships. Undertaking elementary time-series studies of mortality and morbidity over a time period and correlating health impacts with air pollutant concentrations over the same time period. Undertaking elementary cross-sectional studies of the prevalence of health impacts at high, medium and low exposures and correlating them with corresponding air pollutant concentrations considering confounding variables.	The WHO has estimated the global burden of disease due to environmental factors – outdoor air pollution, indoor air pollution, lead, climate change and estimated the corresponding DALYs. Similar estimations were made for each country. The SIM/Air model uses the WHO exposure-response relationships to estimate the number of premature deaths, incidence of diseases. The model has been applied in Hyderabad, India. Time-series studies have been performed in many developed and some developing countries. Cross-sectional studies have been performed in many developed and some developing countries.

Table 1: Summary of low cost tools and policy instruments for air quality management in Sub-Saharan African Countries (cont/)

Component	Objective	Low Cost Option	Description	Examples
Health and Environmental Assessment		Rapid Environmental Impact Assessment Studies	Rapid Environmental Impact Assessment Studies include: Checklists for assessing the potential environmental impact of industries and power plants, especially on agriculture, protected sites, forests and biodiversity. Estimations of the potential threat of O_3 pollution in reducing agricultural crop yields.	Such checklists are being used by Asian Development Bank to categorise the environmental hazard of new projects for chemical-based industrial facilities, mining industries, power plants, roads and highways, and urban development. The Council for Scientific and Industrial Research has developed a dispersion model for such estimates and applied it to estimate O_3 concentrations and their potential impact on crop yield in Southern African Development Community countries.

Table 1: Summary of low cost tools and policy instruments for air quality management in Sub-Saharan African Countries (cont/)

Component	Objective	Low Cost Option	Description
Policies	The overall objective of policy instruments is to include and/or strengthen the concept of air quality management in relevant policies and legislation of SSA cities and countries.		
Industry	To implement strategies to reduce urban industrial emissions.	Ban the import of obsolete technologies from developed countries.	Technologies imported in developing countries should follow the same state-of-the-art technology in developed countries in order to avoid health and environmental impacts that will be more costly to sort out once the technology is installed.
		Set limits on the sulphur content of imported coal.	Sulphur content of imported coal should be below 1 per cent. A low sulphur content in fuels reduces SO_2 and sulphate emissions. The sulphur content of coal does not influence the price on the world market.
		Desulphurisation of the flue gases.	Flue gas desulphurisation in scrubbers is the most cost-effective method to reduce SO_2 emissions in existing power plants and industrial boilers. The polluter pays principle would mean that the owner of the facility would have to cover the costs.
		Use of two-stage combustion; flue gas recirculation; reducing combustion preheat temperature and low excess air to reduce NO_x emissions.	This is a cost-effective method to reduce NO_x emissions in existing gas- or oil-fired plants. This is essentially a change to operating procedures. The polluter pays principle also applies.

Table 1: Summary of low cost tools and policy instruments for air quality management in Sub-Saharan African Countries (cont/)

Component	Objective	Low Cost Option	Description
Industry		Increased energy efficiency in production to reduce overall energy demand leading to lower fuel consumption and lower emissions.	Enhanced energy efficiency leads to better combustions and consequently lower emissions of gaseous air pollutants.
Transport	To implement strategies to reduce urban motor vehicle emissions.	Traffic management	Traffic management measures include computerised traffic light control, network and junction design, parking controls, reducing the supply of space allocated to car parks, speed limits, avoiding obstacles leading to acceleration- and deceleration driving, restricted access for non-essential traffic, bus priority lanes, pedestrian areas and cycling facilities.
		Regulation and control of public bus transport	Use of efficient and comfortable public transport systems can help reduce transport emissions by reducing use of private vehicles. High standards of quality of service need to be implemented.
		Segregated lanes	Segregated lanes can help smooth the traffic flow thus reducing emissions.
		Non-motorized transport (NMT)	NMT is cycling and walking and serves to reduce short-distance car trips which are most polluting. Segregated lanes for motorized transport and NMT are necessary.

Table 1: Summary of low cost tools and policy instruments for air quality management in Sub-Saharan African Countries (cont/)

Component	Objective	Low Cost Option	Description
Transport		Ban the import of obsolete vehicles and phase-out old vehicles still circulation.	Many vehicle fleets in SSA cities are older than 14 years. Obsolete vehicles which would not be licensed anymore in their countries of origin emit 10 times more air pollutants than newer vehicles. A low cost option is to not allow the import of obsolete vehicles and phase-out old vehicles already in circulation.
		Physical restraint.	Physical restraints on vehicle use may take the form of limiting use of vehicles on specific days or in specific areas provided public transport facilities exist.
		Parking policies	Parking policies, including Park and Ride Systems, are likely to reduce both congestion and the demand for individual motorized transport. Effective enforcement of parking restrictions is necessary.
		Road pricing	Tolls on roads and motorways and congestion charges for the access to urban areas help limit car movement provided viable alternatives exist and under-pricing is avoided.
		Use of low sulphur fuels in vehicles	The use of low sulphur fuels in vehicles, particularly diesel vehicles reduces the emission of ultra fine sulphates which are a serious threat to human health due to their carcinogenic properties.

Table 1: Summary of low cost tools and policy instruments for air quality management in Sub-Saharan African Countries (cont/)

Component	Objective	Low Cost Option	Description
Area	To implement strategies to reduce urban emissions from areas sources such as forest fires, burning of biomass and open waste burning.	Ban deliberate open burning in urban areas and at municipal waste deposits.	A ban of open burning in urban areas helps reduce pollutant emissions. A collection, expert deposition and/or treatment must exist in order to enforce the ban.
		Burn municipal and industrial hazardous wastes in existing cement plants at high temperatures.	Hazardous wastes must be treated before deposition of their residues. Municipal waste incinerators are expensive due to the high temperatures of incineration needed. Cement plants use incinerating temperatures high enough to burn most hazardous wastes and produce non-hazardous ashes and residues.
		Collection and use of used tyres as fuel in tar and lime production facilities if they exist or processed in cement kilns.	Open burning of used tyres in urban areas and on waste deposits leads to high PM emissions and should therefore be avoided. Their incineration in tar and lime production facilities or cement kiln avoids this problem.
All sources		Using WHO air quality guidelines to set air quality standards.	The WHO air quality guidelines AQG) can be utilized for setting air quality standards (AQS) in a country. WHO AQG exists for about 80 pollutants. They can be used to set AQS in a stepwise procedure corresponding to the environmental, technological, cultural and financial situation in SSA countries.
		Use of a simple integrated model for air quality management.	The Simple Integrated Model for Better Air Quality (SIM-AIR) is a relatively new interactive model to examine emissions, ambient air quality and health.

Table 1: Summary of low cost tools and policy instruments for air quality management in Sub-Saharan African Countries (cont/)

Component	Objective	Low Cost Option	Description
Transboundary	To implement strategies to reduce emissions which contribute to: regional haze from forest fires, atmospheric brown cloud (ABC), acid deposition, regional dust and the importation of hazardous waste.	Use of low-sulphur fossil fuels (low sulphur coal and oil, and natural gas).	Combustion of low sulphur fuels in industries and motor vehicles reduces the emission of ultra fine sulphates which are a serious threat to human health.
		Use of low excess air NO_x burners in industries can help to reduce NO_x emissions during combustion.	This is a cost-effective method to reduce NO_x emissions in existing gas- or oil-fired plants and is essentially a change in operating procedures. The polluter pays principle should always apply but in the case of transboundary pollution agreements among countries are needed.
		Use of flue gas desulphurisation and denitrification to remove the pollutants from flue gas.	New plants to be installed in SSA countries should employ state-of-the-art technology as in developed countries with respect to desulphurisation and denitrification in order to avoid cost-intensive *a posteriori* measures or be forced to accept human health and environmental impacts.
		Ban the importation of hazardous chemicals and hazardous wastes by implementing Amendment Decision III/1 to the Basel Convention and the Bamako Convention.	A ban on the importation of hazardous chemicals and hazardous wastes from developed countries to SSA avoids the 'social dumping' of hazardous materials which cannot be properly treated in developing countries. Thus, all SSA countries should adopt Amendment Decision III/1 to the Basel convention and the Bamako convention.

Table 1: Summary of low cost tools and policy instruments for air quality management in Sub-Saharan African Countries

Component	Objective	Low Cost Option	Description
		For vehicle emission reduction, low sulphur fuels and NO_x control devices can be applied.	The use of low sulphur fuels in vehicles, particularly diesel vehicles reduces the emission of ultra fine sulphates. NO_x control devices (catalysts) reduce NO_x emissions and limits O_3 chemical conversion. A prerequisite for effective NO_x control is the supply of fuels of appropriate quality and existence of an enforced inspection and maintenance system.
Climate Change	To implement strategies to reduce greenhouse gas emissions which contribute to global climate change.	Implement measures to achieve co-benefits in the reduction of urban air pollutants and greenhouse gas (GHG) emissions.	Many measures of air pollution reduction also reduce GHG emissions. Such measures include cleaner production technologies, cleaner fuels and vehicles, and demand management of goods and services.
		Use the Clean Development Mechanism (CDM) as an instrument to implement co-benefit measures	The use of the CDM can lead to increased energy efficiency and conservation; transfer of technologies and financial resources; local environmental and human health benefits. Subsequent benefits will include sustainable energy production; private and public sector capacity development; and poverty alleviation and equity realisation through income and employment generation.

Chapter 1

Introduction

Air pollution in Sub-Saharan Africa (SSA) appears to be on the rise with respect to many key pollutants. In some SSA cities where monitoring has been performed levels of urban air pollution exceed World Health Organization (WHO) recommended guidelines (WHO, 2005). The main cause of urban air pollution is the use of fossil fuels in transport, power generation, industry and the domestic sector. In addition, the burning of firewood, agricultural and animal waste also contributes to pollution levels. Pollutant emissions have direct and indirect effects (e.g. acidification, eutrophication, tropospheric ozone and stratospheric ozone depletion) with a wide range of impacts on human health, ecosystems, agriculture and materials.

Air pollution can come from both man-made and natural sources. Sources include stationary/point sources (e.g. major industrial sites); area (non-point) sources (e.g. domestic emissions and emissions from light industry, commercial areas, waste deposits, and open fires); mobile (line) sources (e.g. motor vehicles); and natural sources (e.g. dust storms, forest fires and volcanic eruptions).

Urban air pollutants can be divided into two groups: traditional air pollutants for which air quality standards normally exist, and hazardous air pollutants. Traditional air pollutants comprise nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), particulate matter (PM), ozone (O_3) and lead. Hazardous air pollutants (HAPs) consist of chemical, physical and biological agents. HAPs are present in the atmosphere in much smaller concentrations and are often more localized, but are toxic or hazardous in nature. HAPs include a range of hydrocarbons, e.g. benzene, toluene and xylenes, and other toxic organic pollutants such as polycyclic aromatic hydrocarbons (PAHs), pesticides, polychlorinated biphenyls (PCBs), dioxins and furans (USEPA, 2007).

Air pollutants can also be further classified into primary and secondary pollutants, according to their origin. Primary pollutants are those emitted directly to the atmosphere (e.g. SO_2, CO and soot) while secondary pollutants (e.g. O_3) are those formed by reactions involving other pollutants. Polluting air emissions from transport, power generation, industry, and the domestic sector contain both noxious pollutants which are deleterious to human health, and greenhouse gases (GHGs) which contribute to climate change. Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and three groups of fluorinated gases (sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs)) are the major GHGs and the subject of the Kyoto Protocol. Emissions of air pollutants and GHGs have direct (e.g. visibility) and indirect (e.g. acidification, ozone depletion and climate change) effects on air quality with a wide range of impacts on human health, ecosystems, agriculture and materials.

Many people are vulnerable to the adverse effects of air pollutants because they are highly exposed to pollutants and/or have increased sensitivity to exposure. Vulnerability is defined as the extent to which people are susceptible to sustaining damage from air pollution. Vulnerability is a function of the sensitivity of the weakest sub-populations (e.g. children, older people or the sick) to changes in air quality. The degree to which individuals are affected by changes in air quality, including harmful and beneficial effects, determines their overall sensitivity. A study of the global burden of disease demonstrated that 67 per cent of the estimated number of deaths for acute respiratory diseases occurs before 15 years of age (Murray and Lopez, 1996).

The world's poorest people suffer most from adverse environmental conditions and are exposed to high levels of indoor as well as outdoor air pollution. Most of the poor, especially in the less developed countries in Africa, live and work in rural areas and in informal settlements at the margins of expanding urban centres.

1.1 Urban Air Pollution in Sub-Saharan Africa

Urban outdoor air pollution is responsible for an estimated 63,000 premature deaths each year in Africa. The indoor use of solid fuels is responsible for 7.5 times this value (WHO, 2002; 2006). Air pollution, outdoor and indoor, affects the health and life chances of millions of people in SSA every day. There is a link between air pollution and poverty since poor people are exposed to higher concentrations of air pollutants and tend to suffer disproportionately from the effects of deteriorating air quality. Children exposed to high concentrations of air pollutants often develop respiratory ailments which can prevent them from learning. As a consequence they will suffer in adult life from low levels of qualifications and skills. The implication of poorly educated children not only affects the quality of their lives but is also an obstacle for the economic development of a country as a whole.

African urban population growth rates (see Figure 1.1) have been and will continue to be the highest in the world (See Annex 1 for a definition of the SSA regions). African city-based population percentages are also growing faster than in cities in all other regions of the world and are estimated to continue to do so in the next two decades and beyond.

Rapid urbanization means increase an in motorization (see Figures 1.2 to 1.7) and economic activity which in turn leads to increased air pollution if counter measures are not taken. In addition to water and solid waste problems, SSA is facing substantial challenges in terms of urban air quality. These challenges include polluting old vehicles, lack of proper vehicle maintenance and cleaner fuels, a poor regulatory vehicle emission framework and poor enforcement of laws and regulations when they exist. Table 1.1 presents the key challenges of urban air pollution in SSA.

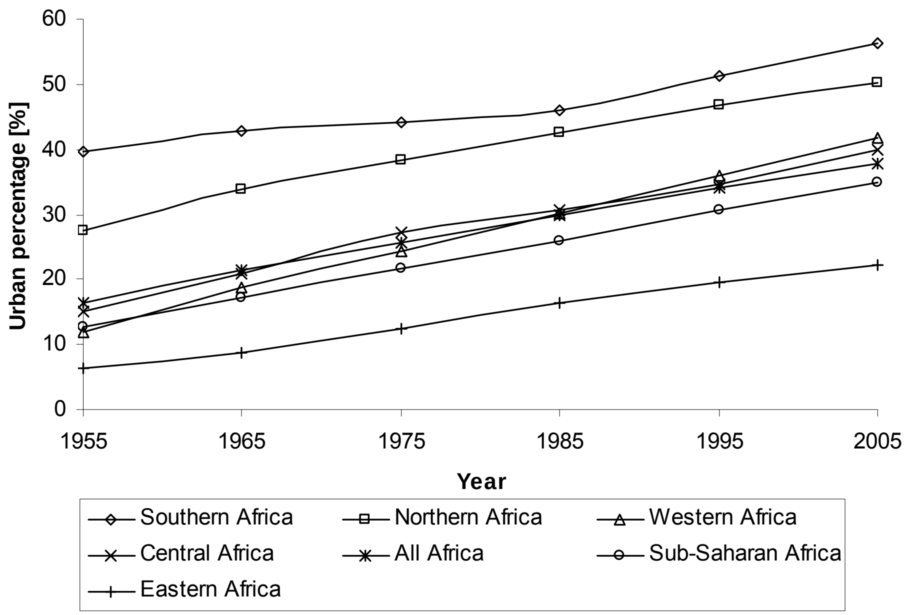


Figure 1.1: Percentage of urban population in regions of Sub-Saharan Africa
Source: UN (2007)

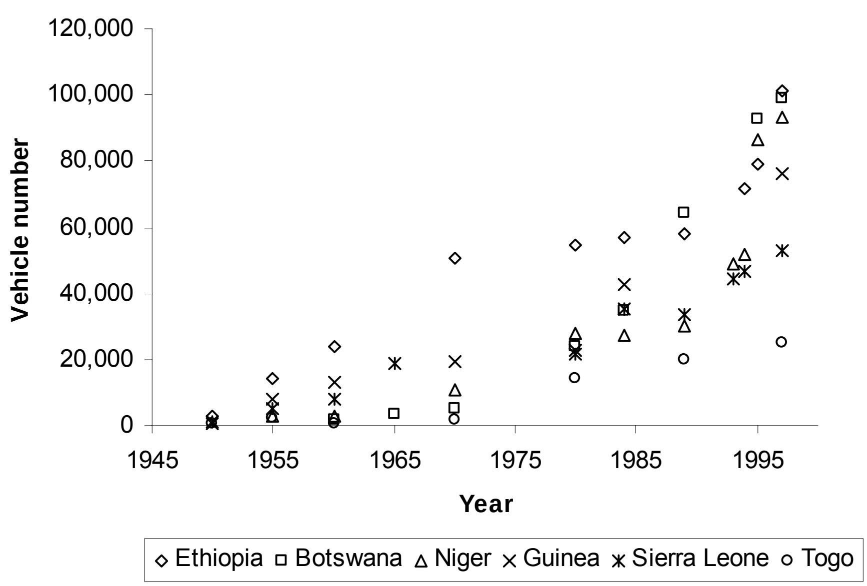


Figure 1.2: Vehicle growth in selected SSA countries 1950-1998
Source: Archondo-Callao (2000)

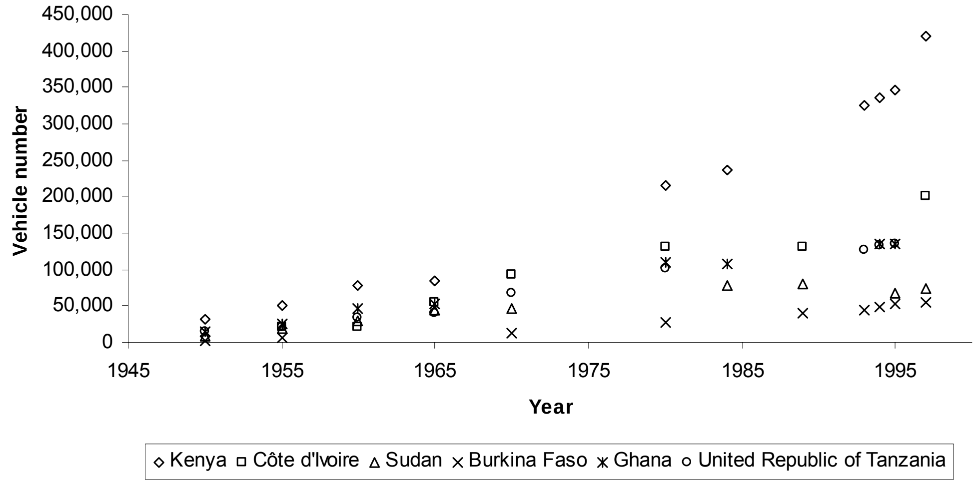


Figure 1.3: Vehicle growth in selected SSA countries 1995-1998
Source: Archondo-Callao (2000)

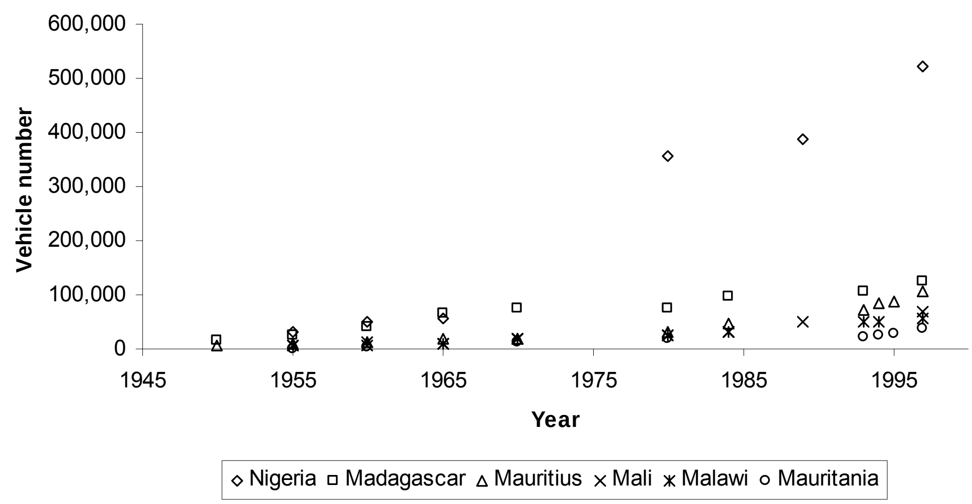


Figure 1.4: Vehicle growth in selected SSA countries 1995-1998
Source: Archondo-Callao (2000)

Table 1.1: The challenge of urban air pollution in Sub-Saharan Africa

Driving Forces	Rapid growth of the population, urbanization (see Table 1.2 and Figure 1.1), migration, motorization, striving for economic growth.
Pressure	The rapid growth in vehicle fleets and two-wheelers (motor bikes and mopeds) is a major source of urban air pollution. Figures 1.2 to1.5 show vehicle growth for the period 1950 to 1998. Figure 1.6 shows the projected increase in vehicle kilometres travelled for light duty vehicles and two-wheelers for the period 2000 to 2050 while Figure 1.7 shows the projections in vehicle ownership. Vehicles in SSA cities are poorly maintained and on average are approximately 14 years old. Insufficient and poorly maintained infrastructure contributes to the problem of re-suspended dust emissions. Petroleum products in certain markets are of dubious quality as adulteration is common practice.
State	Emissions inventories for air pollutants are lacking in almost all countries. Initial estimations exist for greenhouse gases which were developed to fulfil the obligations of the Climate Change Convention. Air quality monitoring in urban areas is often not performed. If monitoring networks are installed they are hampered by the breakdown of monitoring devices and an unpredictable power supply. Botswana, Ethiopia, Ghana, Guinea, South Africa, Tanzania, Zambia and Zimbabwe reported that they are monitoring routinely or have ad hoc monitoring campaigns. Key pollutants include particulate matter, nitrogen dioxide, sulphur dioxide, carbon monoxide, volatile organic compounds and hydrocarbons.
Impacts	Impact of air pollutants on human health and the environment are rarely assessed in SSA countries. Out of the 27 countries considered in Schwela (2007) only Nigeria reported that a human health impact survey was performed and other studies addressed acid precipitation, pollutant levels in biological species, and the urban climate.
Response	Policies on environmental protection have been developed in the majority of SSA countries and take the form of an Environment Act which also covers air pollution. The Environment Act is complemented by regulations and rules which specify fuel parameters and emission standards. Most SSA countries address air quality management in an ad hoc fashion. This procedure bears the risk of making wrong decisions. Only Madagascar appears to have developed a full-fledged air quality management system addressing revision of legislation, emissions, dispersion, air pollutant concentrations, control measures, impacts and cost-benefit analysis. Ghana and Tanzania are on the way to developing an air quality management system.

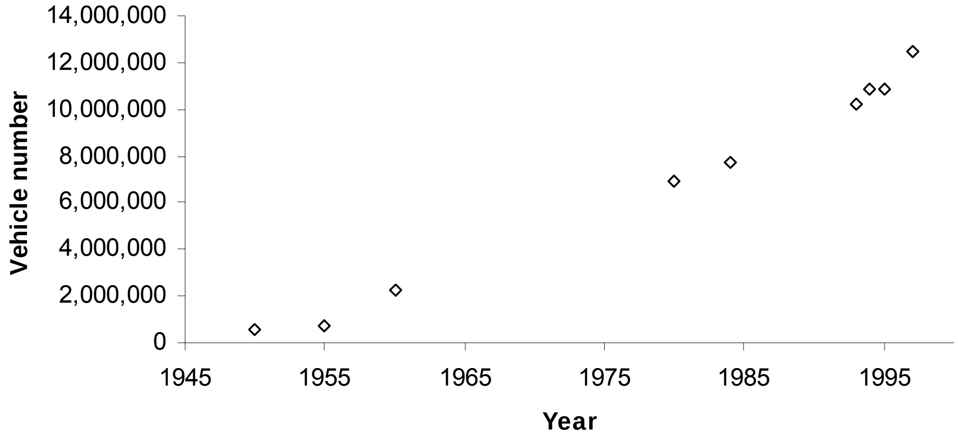


Figure 1.5: Vehicle growth in South Africa 1995-1998
Source: Archondo-Callao (2000)

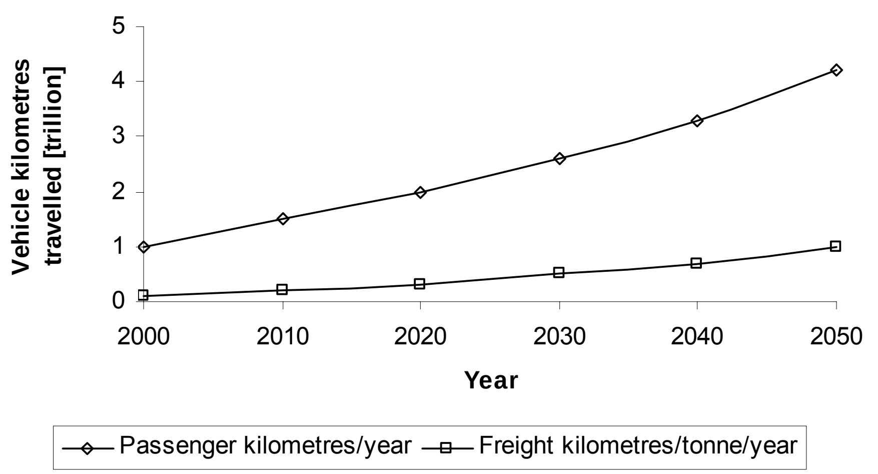


Figure 1.6: Projections of vehicle kilometres travelled of light duty vehicles and two wheelers in Africa (2000-2050)
*Source***:** WBCSD (2004)

Table 1.2: Percentage of urban population in Sub-Saharan Africa

Country	1955	1965	1975	1985	1995	2005
Angola	8.9	12.5	19.1	30.3	44.0	54.0
Benin	6.8	12.5	21.9	30.8	36.8	40.0
Botswana	2.9	3.8	11.9	26.7	49.0	57.3
Burkina Faso	4.2	5.2	6.3	12.3	15.1	18.3
Burundi	1.9	2.2	3.2	5.2	7.2	9.5
Cameroon	11.4	16.9	27.3	36.2	45.3	54.3
Cape Verde	15.4	18.1	21.4	31.5	48.8	57.4
Central African Republic	17.1	23.5	32.0	35.5	37.2	38.1
Chad	5.5	8.4	15.6	19.8	21.9	25.3
Comoros	9.2	17.0	21.2	25.5	28.3	27.9
Congo (Brazzaville)	28.1	35.3	43.3	52.2	56.4	60.2
Congo (Kinshasa) DR	20.7	26.1	29.5	28.0	28.4	32.1
Cote d'Ivoire	13.1	24.5	32.2	38.3	41.4	46.8
Djibouti	45.0	56.1	67.1	74.6	79.7	86.1
Equatorial Guinea	20.4	26.5	27.4	29.9	38.8	38.9
Eritrea	8.3	11.4	13.5	15.2	16.6	19.4
Ethiopia	5.4	7.6	9.5	11.5	13.9	16.1
Gabon	14.1	23.8	43.0	62.4	75.4	83.6
Gambia, The	11.2	14.5	24.4	33.0	43.8	53.9
Ghana	19.1	26.1	30.1	32.9	40.1	47.8
Guinea	8.4	13.0	19.5	26.6	29.5	33.0
Guinea-Bissau	11.7	14.3	16.0	22.4	29.8	29.6
Kenya	6.4	8.6	12.5	17.0	19.0	20.7
Lesotho	1.9	6.3	10.8	11.8	17.0	23.3
Liberia	15.6	22.1	30.4	40.3	50.0	58.1
Madagascar	9.1	12.4	16.3	20.9	25.8	28.5
Malawi	3.9	4.9	7.7	10.2	13.3	17.3
Mali	9.7	12.6	16.2	21.0	25.5	30.5
Mauritania	4.6	10.1	20.6	35.0	39.8	40.4
Mauritius	30.9	37.0	43.4	42,3	43.3	42.3
Mozambique	3.0	4.6	8.7	16.7	26.2	34.5
Namibia	15.5	20.0	23.7	26.4	29.8	35.1
Niger	5.3	6.8	11.4	14.5	15.8	16.3
Nigeria	12.3	20.1	25.5	31.8	38.9	46.2
Rwanda	2.1	2.8	4.0	5.1	8.3	17.5
Sao Tomé e Principe	14.7	21.8	31.6	38.0	48.6	58.1
Senegal	20.0	26.4	33.7	37.5	39.8	41.6
Seychelles	27.5	33.1	46.3	49.3	49.9	52.9
Sierra Leone	14.9	20.2	26.8	31.6	34.2	36.8
Somalia	14.9	20.0	25.5	28.1	31.4	35.2

Table 1.2: Percentage of urban population in Sub-Saharan Africa (cont/)

Country	1955	1965	1975	1985	1995	2005
South Africa	44.4	47.2	48.1	49.4	54.5	59.3
Sudan	8.6	13.4	18.9	22.4	31.3	40.8
Swaziland	2.4	6.5	14.0	21.8	23.0	24.1
Tanzania	4.4	6.0	11.1	16.8	20.5	24.2
Togo	6.7	15.0	22.9	27.2	33.2	39.9
Uganda	3.5	5.5	7.0	9.2	11.7	12.5
Zambia	14.5	23.4	34.9	39.7	37.1	35.0
Zimbabwe	11.6	14.6	19.9	25.4	31.7	35.9

Source: UN (2007)

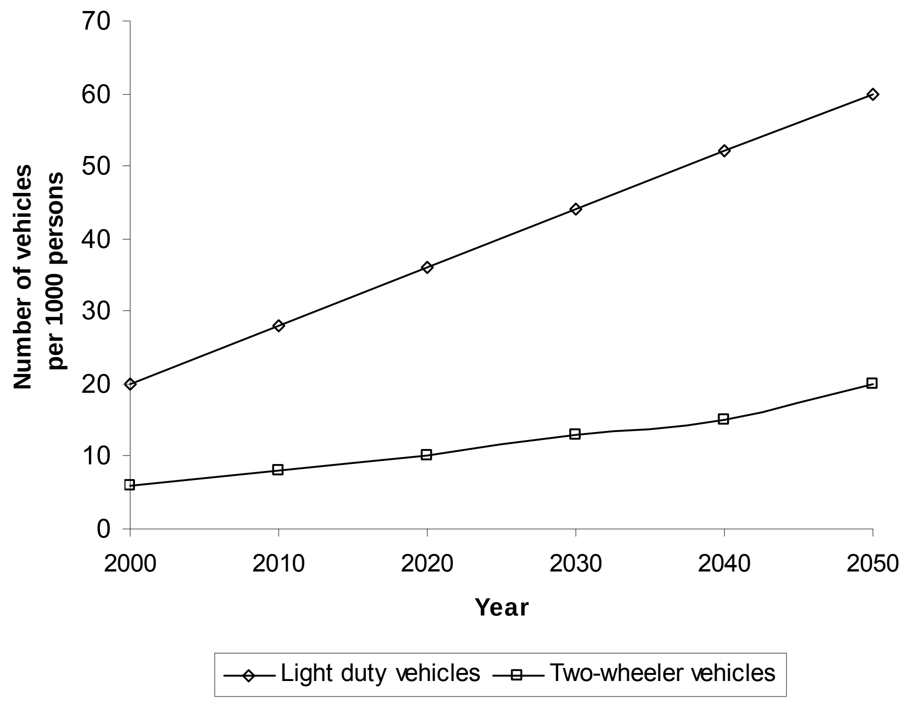


Figure 1.7: Projection of vehicle ownership in Africa per 1000 inhabitants (2000-2050)

Source: WBCSD (2004)

Clean air is recognised as a key component of a sustainable urban environment in international environmental agreements and increasingly in regional environmental declarations. Agenda 21, a result of the 1992 United Nations Conference on Environment and Development (UNCED), supports a number of environmental management principles on which governmental policies should be based, and promotes the adoption of national action programmes of urban air pollution (UNCED, 1992). In 2002 the World Summit on Sustainable Development (WSSD) further recognised the problem of air pollution in Section IV 37 of its Plan of Implementation which requests states to enhance cooperation at the international, regional and national levels to reduce air pollution, including transboundary air pollution, acid deposition and stratospheric ozone depletion. The Plan also acknowledges the significant impact of air pollution on human health in particular respiratory diseases and other health impacts resulting from air pollution, with special attention to women and children (WSSD, 2002).

In some SSA countries national and local governments have begun to develop air quality management strategies to address the deterioration in urban air quality. However, the scope and effectiveness of such strategies vary widely between countries and cities. In order to achieve better air quality in SSA, appropriate policies and strategies to prevent and control air pollution need to be developed and implemented.

Challenge of urban air pollution

An assessment of urban air pollution in 27 SSA countries (Schwela, 2007) identified the key challenges to achieving better air quality in SSA cities. The assessment showed the challenges to managing air quality range from a lack of government commitment and stakeholder participation, weaknesses in policies, standards and regulations, through to deficiencies in data on emissions, air quality and impacts on human health and the environment. Emissions inventories are often absent, incomplete or inaccurate. Emissions standards are sometimes obsolete and do not reflect best technical practice. Measures to prevent and reduce air emissions are often hampered by lack of source apportionment. Low cost and effective alternative technologies are rarely available. Outdoor air quality monitoring systems are often limited in spatial coverage, are not harmonised or are absent altogether while transboundary air pollution is rarely monitored.

The lack of quality assurance/quality control procedures in emission estimates and monitoring data means that data quality is often unknown, or poor. In many African countries insufficient information exists on the health, environmental and economic impacts of air pollution. Risk perception, risk communication, information dissemination and awareness raising are often issues which need to be addressed. The relatively low priority given to managing air quality means that funding is often a problem. Key barriers to the adoption and implementation of the air quality management policies include lack of sufficient political will, inadequate infrastructure, lack of reliable emissions data and air quality monitoring and poor surveillance of air pollution related health impacts.

There is a growing need in SSA to determine the state of urban air quality and overcome the challenges posed to improving air quality. This involves identifying the most effective measures to protect human health and the environment. The issue of urban air quality was the subject of a regional conference on Better Air Quality in Sub-Saharan African Cities (BAQ-Africa 2006) which was held in Nairobi, Kenya in June 2006. The conference was supported by the Air Pollution Information Network for Africa (APINA), Stockholm Environment Institute (SEI), the World Bank's Clean Air Initiative in Sub-Saharan African Cities (CAI-SSA), United Nations Environment Programme (UNEP), United States Environment Protection Agency (USEPA), United States Agency for International Development (USAID), Swedish International Development Cooperation Agency (SIDA) and the International Atomic Energy Agency (IAEA).

The conference brought together experts, policy makers and decision makers. Approximately 40 SSA Ministers, representatives from international organizations, the private sector, and non-governmental organizations (NGOs). The conference recognised the importance of achieving better air quality in SSA cities and identified the need to:

- develop legal and regulatory frameworks to address for better air quality in SSA;
- mainstream air quality management in poverty reduction and growth strategies;
- address air quality issues jointly among countries as air pollution is trans-boundary;
- lower sulphur levels in fuels. However, more information regarding the costs and ramifications of lowering sulphur levels should be made available to facilitate an agreement on specific targets and timeframe at sub-regional level, similar to the preparations for the lead phase out agreement;
- integrate air quality management to other sectors of the economy such as health, industry, transport, finance and urbanization;
- manage the quality of vehicles being imported into the region to control vehicle emissions. It is also important to have in place mechanisms for testing, inspection and maintenance of existing vehicle fleets to achieve better air quality;
- address issues of indoor air pollution.

In addition, the conference recognised the need for:

- policy makers to spearhead better air quality management in their countries and that this should be addressed in the context of economic development;
- key areas to be encompassed in air quality management such as burning of solid waste and plastic waste, industrial air pollution and mining activities;
- mass transport and better municipal and town planning, including greening of cities to address air quality. In particular, a majority of people in SSA live in unplanned settlements, commonly referred to as slums, which also have specific issues of air pollution that need to be addressed from a policy perspective and with strategic planning;
- capacity to monitor and assess the present state and impacts of air pollution in the countries in SSA.

In 2008, participants of the fourteen Southern African Development Community (SADC) countries, representing government, industry, NGOs, civil society, international organisations and academia attended the Southern Africa Sub-Regional Policy Dialogue on Air Pollution in Lusaka, Zambia, 5-6 March 2008. The participants developed a Regional Policy Framework that was subsequently adopted by SADC Ministers at the Ministerial Session on 7 March 2008 as the Draft SADC Regional Policy Framework on Air Pollution (UNEP, 2008). The Lusaka Agreement further elaborated the needs identified at BAQ 2006 as follows:

1 Multilateral Co-operation

- Endeavour to work together for the preparation of a multilateral agreement with flexible and differentiated obligations for the control and ultimate reduction of agreed air pollutants.
- Consider synergies and co-benefits of taking joint measures against emissions of air pollutants and greenhouse gases.
- Harmonise among the States as far as it is practical, national legislation and air quality standards, monitoring procedures and air quality data management procedures.
- Promote the exchange of information, education and research within the SADC region.

2 Transport Sector

- ***Cleaner Fuels***
  - Enact regulations to reduce sulphur levels in diesel to 500 ppm (parts per million) by end of 2010, as an intermediate step for countries that import refined fuel.
  - Enact regulations to reduce sulphur levels in diesel to 50 ppm from 2010 onwards for both refining and importing countries.
  - Promote the harmonisation of fuel standards.
  - Complete the phase-out of leaded gasoline; and phase-out the use of other harmful metallic additives.
  - Enforce regulations against procurement, sale and use of fuels not meeting current fuel specifications.
  - Carry out scientific assessments of energy economics, environmental and socio-economic consequences before shifting to significant use of bio-fuels.
- ***Cleaner Vehicles***
  - Enact regulations to require that all used vehicles imported into the region from 2010 onwards should be equipped with a functional catalytic converter.
  - Enact regulations to require that all new vehicles imported into or manufactured in the region should meet a regionally agreed minimum emissions standard by the end of 2010.
  - Enact regulations to restrict the age of vehicles imported into the region to a maximum of 10 years.
  - Enact regulations for vehicle emissions testing, maintenance and inspection to ensure that vehicles comply with the agreed emissions standards.
  - Implement cleaner vehicle technologies, for example compressed natural gas or diesel retrofits, in large fleets.
  - Enact regulations to require that all diesel powered on-highway trucks and buses that are more than 10 years old are equipped with diesel retrofit devices.
  - Require that vehicles crossing international borders for goods or passenger conveyance comply with these regional emission standards.
- ***Urban Planning***
  - Support land use planning policies for sustainable mobility.
  - Plan for and promote safe, attractive and affordable public and non-motorized transport that is interconnected.
  - Allocate an equitable share of road development funds and investments for non-motorized transport.

- Consider controlling passenger car use through appropriate measures like road pricing, congestion charging and parking management.

3 Industry

- Encourage regional cooperation to address national and transboundary air pollution issues, through harmonisation of legal frameworks for air quality management of industrial emissions across SADC, including specific criteria and procedures for point source emission permitting and monitoring.
- Promote the use of best available technology for new industrial plants so as to meet requirements of the harmonised legal frameworks.
- Maximise the synergies and co-benefits of air pollution and climate change mitigation projects.
- Enact regulations that require industry to undertake environmental impact assessments and audits in line with the requirements from the harmonised legal frameworks.
- Enact regulations that require industry to retro-fit old plants with necessary equipment so as to comply with the requirements of the harmonised legal frameworks, or alternatively to phase out obsolete plants over appropriate timescales.

4 Open Burning

- ***Vegetation Fires, Uncontrolled Burning and Deforestation***
  - Support investigations into the frequency and impacts of natural fires in the
  - African savannah and forests.
  - Enact regulations to prevent and control human initiated vegetation wild fires.
  - Develop and implement fire early warning systems and fire management strategies.
  - Promote reforestation programs in damaged landscapes.
- ***Waste Management***
  - Develop and implement integrated waste management systems.
  - Enact regulations to prevent uncontrolled combustion of waste.

5 Indoor Air Pollution

- Promote the use of more efficient, cleaner burning and safer energy appliances.
- Promote the use of cleaner fuels, where feasible, for social, cultural, economic and other reasons.
- Formulate recommendations and guiding principles for domestic indoor air quality.
- Formulate recommendations and emission standards for combustion appliances.
- Formulate recommendations and guiding principles for construction of properly ventilated, energy efficient houses.
- Formulate indoor air quality standards for public and commercial facilities.
- Support establishment of sustainable supply of cleaner burning appliances.
- Support financing of indoor air quality improvement.
- Enact legislation to prevent smoking in indoor public places, and outdoor gathering locations.

6 National Environmental Governance

- Develop policies, laws and regulations with respect to air quality management, integrated with relevant Conventions and Treaties.
- Create or enhance national environmental agencies, to include air quality management divisions.
- Create or enhance an inspectorate branch to enforce air quality and emissions regulations.
- Develop and maintain surveillance and data systems for recording air pollution impacts on public health, crops, materials and ecosystems, using harmonised regional approaches.
- Develop and maintain national emissions inventories for main pollutants and greenhouse gases, and assess the impact of different policies and measures on these emissions.
- Establish at least one air quality monitoring station per country, using harmonised regional instrumentation and protocols, and link this with modelling efforts in the region.
- Enact regulations for industry to monitor their emissions and provide the data and calibration certificates to regulatory agencies as required.
- Facilitate the harmonisation of air pollution standards within the SADC region.
- Undertake periodic reviews to benchmark regional national air quality standards against best international practice.
- Undertake periodic state-of-atmospheric environment reports to determine if standards and targets are being attained.
- Harmonise policies and management strategies that impact the atmospheric environment across key governmental agencies, for example departments of energy, health, agriculture, planning, finance and transportation.

7 Public Awareness

- Increase public awareness on air pollution issues using all formal and informal communication channels.
- Enhance public participation on air pollution issues by capacity development (education and training) in governmental, educational, and civil society organisations.
- Engage civil society and other stakeholders on collaborative air pollution projects.
- Promote accessibility to information on air pollution issues and exchange of information, education and research on air pollution.
- Develop effective communication strategies on air pollution impacts on human health and the environment.
- Promote advocacy, public awareness and participation concerning indoor air quality and domestic energy management.

8 Research, Development and Capacity Building

- Promote and establish regional training centres on air quality management and related issues.
- Promote and establish regional centres of excellence on air quality management research and related issues.
- Promote and support regional postgraduate training and student exchange programmes within the region and with international partners on air quality management and related issues.

- Promote and support the inclusion of air pollution in environmental impact studies and socio-economic assessments in collaboration with local and international academic institutions.
- Promote and establish initiatives for reducing air pollution in collaboration with international organizations (such as Global Atmospheric Pollution Forum, UNEP, USEPA, World Health Organization, World Meteorology Organization, World Bank) and other regional air pollution networks.
- Support the application of harmonised emissions inventories, monitoring and modelling, impact assessment, mitigation options and policy framework approaches through organisations such as the APINA) in collaboration with international partners.
- Establish a regional air quality information system.
- Conduct economic analysis to develop and optimise alternative scenarios and options, which include air pollution, to guide development policies consistent with sustainability.
- Continue the regional dialogue on transboundary transport of air pollution and urban air pollution through APINA, with appropriate logistic and financial support.

These provisions can only be implemented overtime subject to the stage of development and economic circumstances of each of the SADC member countries.

1.2 Structure of Report

This Handbook identifies the main low cost solutions available to achieve better air quality in SSA. It outlines the low cost tools and policy instruments which can assist SSA countries and cities to develop and/or improve action to prevent further deterioration of air quality. Low cost is defined in the broadest sense of the term as it is not feasible to provide a detailed economic assessment of each tool/policy instrument identified. Low cost in this Handbook refers to a low demand on financial, human and data resources. The options identified provide the easiest way to achieve emission reductions within the socio-economic constraints that many SSA countries currently face. The different tools and policy instruments for better air quality should be implemented as part of a strategic approach to air quality management.

This Handbook builds upon the United Nations Environment Programme (UNEP) and United Nations Human Settlements Programme's (UN-HABITAT) *Urban Air Quality Management Toolbook* and the *Toolkit for urban air quality management* (UNEP, 2005) and the *Sustainable Transport Sourcebook for Policy makers in Developing Cities* (GTZ, 2002). It is aimed at stakeholders and advisors to policy makers in SSA. It provides a strategic set of priority measures and actions (e.g. policy instruments, low sophistication technologies) which can be easily implemented at the national and regional level. Because of limited financial resources, SSA countries should focus on selected key pollutants and sources. Thus strategies to improve air quality in SSA may be quite different from those adopted in other richer countries.

The Handbook consists of nine chapters including this introduction. Chapter 2 discusses the key features of an air quality management framework. Chapters 3-6 examine the features of emissions, modelling, monitoring and health and environmental assessment. For each component low cost tools are identified. Chapter 7 reviews the policy instruments available to achieve better air quality in SSA cities. It highlights the low cost policy instruments than can be taken to reduce polluting air emissions from industrial, transport and area sources. It also examines the actions available to address transboundary air pollution and climate change.

Chapter 2

Air Quality Management

Air quality management (AQM) aims to maintain and/or achieve a level of air quality which protects human health and the environment. Improvement of poor air quality is necessary to enable further growth of developing countries as air pollution impacts heavily on human health and the environment resulting in high financial costs. Many countries which have developed an effective AQM approach have discovered that the benefits received from emission reductions are usually much higher than the costs of implementing emission reduction measures.

AQM is based on a set of guiding principles which include the 'prevention', 'precautionary' and 'polluter pays' principles (see Table 2.1). It aims to maintain the quality of the air that protects human health and welfare but also provides protection of animals, plants (e.g. crops, forests and natural vegetation), ecosystems and materials.

Benefits of Air Quality Management

AQM enables government authorities, in collaboration with other stakeholders, to:

- identify and establish appropriate policies on air quality;
- identify and develop relevant legislative and regulatory requirements;
- identify all major sources of air pollution caused by human activities;
- set appropriate objectives and targets for human and environmental health;
- set priorities for achieving objectives and targets;
- establish an institutional structure and programmes to implement policies and achieve objectives and targets;
- facilitate the monitoring of air quality and effects on human health and the environment;
- facilitate urban planning, corrective action and the prevention of adverse effects;
- ensure compliance with emission and air quality standards; an
- account for changing circumstances.

Table 2.1: Guiding principles of air quality management

Access to environmental information: all stakeholders should have access to information regarding air quality.

Awareness: knowledge of stakeholders of the seriousness of air pollution, its causes and possible preventive and remedial measures.

Best practice: application of best available technology.

Coherence: orientation of the efforts of all stakeholders, including different neighbouring jurisdictions, towards a common objective.

Concerted effort: discussion and cooperation among all stakeholders involved in the implementation of AQM measures.

Compatibility: development of AQM compatible with regional, national and local needs.

Continual improvement: to promote the continual improvement of AQM as well as air quality itself.

Cost-effectiveness: AQM measured at minimum cost but high effectiveness.

Decentralization: implementation of decentralized AQM, regional, national and local components, and due consideration to local capacity.

Equity: fair and equal protection of all people from air pollution and consideration of individual vulnerability.

Integrated approach: development of comprehensive and integrated AQM (prevention, monitoring of adverse impacts, control of sources and education).

Market: apply market mechanisms, as far as possible.

Opportunity: sound solutions to air quality problems at the most suitable moment.

Participation: active participation of different stakeholders, including the general population, in the development and implementation of the plans to minimize air pollution and prevent the deterioration of air quality.

'Polluter pays' principle: individuals or entities responsible for pollution should bear the cost of its consequential impacts.

'Precautionary' principle: where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

Stakeholder: commitment of all stakeholders to AQM.

Sustainability: development of economically, socially and environmentally compatible AQM which is sustainable over the long-term.

Stepwise approach: AQM following a target and milestone approach.

Universality: comprehensive AQM, including human health and the environment.

Source: SEI/KEI (2004)

An effective AQM strategy is dependent on a number of factors. These include emission inventories, air quality monitoring networks, air quality prediction models, exposure and damage assessments, as well as health and environment-based standards. Along with these factors are a range of cost-effective pollution control measures and the legislative powers and resources to implement and enforce them. Figure 2.1 presents a simplified framework for AQM.

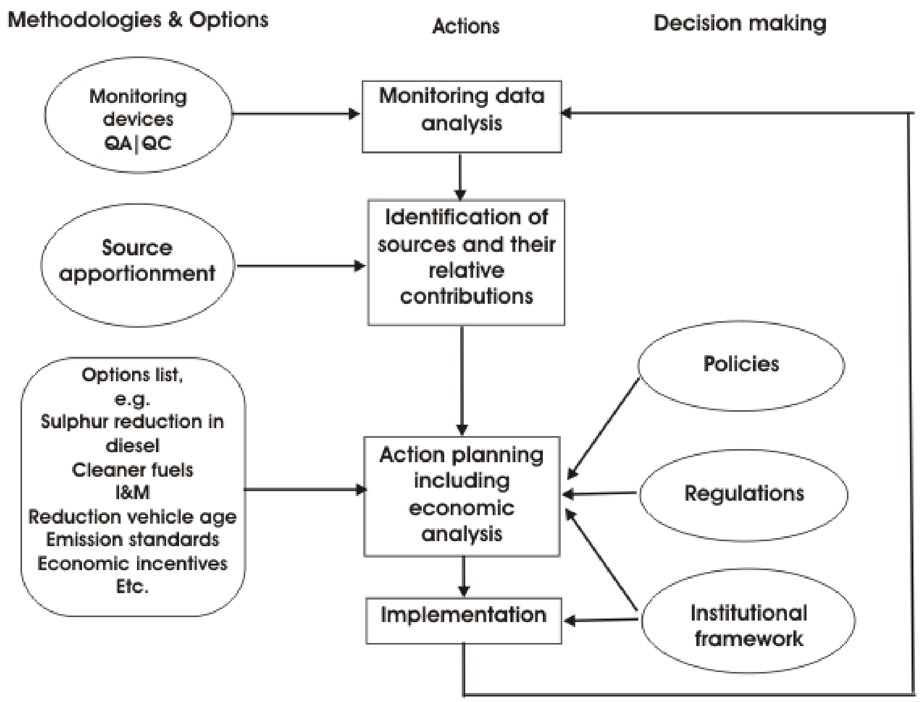


Figure 2.1: Simplified framework for air quality management

AQM is a dynamic and iterative process which typically starts with the definition of outdoor (ambient) air quality standards or guidelines. In order to assess the levels of air pollution in a specific geographical area or region, the next steps will be to perform ambient air quality monitoring and derive emissions inventories. From the results of ambient air monitoring networks, the compliance with air quality standards and potential impacts can be assessed. The emissions inventory is one of the crucial components of AQM. An emissions inventory is a reasonable quantitative assessment of the emission loads from relevant sources/sectors that can be used to identify the most important sources and options for control. The quantification of emissions can also be used as an input to dispersion modelling to predict ambient air concentrations from different emission sources and to determine the health and environmental impact.

Due to limited availability of financial and human resources and data on air pollution in many SSA countries, it is necessary to identify solutions which can be implemented within the SSA context. In this Handbook an attempt has been made to identify low cost tools and policy instruments to achieve better air quality in SSA cities. Low cost is defined as placing a low demand on financial, human and data resources. The tools examined include simple rapid assessment techniques to gain an understanding of the type and concentration of air emissions and their impact on human health and environment. As well as a range of policy instruments which, if implemented and enforced, could achieve a relatively quick reduction in polluting air emissions. Table 2.2 presents a summary of low cost tools for AQM in SSA which are discussed further in the following chapters. Table 2.3 presents a summary of the low cost policy instruments available. These tools and policy instruments should form part of an integrated AQM strategy which should be formulated in cooperation with national, regional and local authorities and the different groups of stakeholders that contribute to the problem.

Table 2.2: Summary of low cost tools for air quality management in Sub-Saharan African Countries

Component	Objective	Low Cost Option	Description	Examples
Emissions	The objective for emission reduction is to include and/or strengthen enforceable, affordable, sustainable and highly effective measures to assess and reduce emissions. These include: • short-term strategies to reduce emissions to adequately address the overall problem; • use of end-of-pipe and best available control technology solutions to prevent pollution; and • effective measures to reduce air pollution which are fully coordinated with other measures.	Rapid Emission Inventories	An emissions inventory is generally defined as a comprehensive listing of sources and an estimation of the magnitude of air pollutant emissions in a geographic area during a specific time period. Rapid Emission Inventories provide a simplified and user-friendly framework for emissions inventory preparation. Rapid Emission Inventories are suitable for use in different developing and rapidly industrialising countries and are compatible with other major international emissions inventory initiatives.	Global Atmospheric Pollution Forum's rapid emission inventory manual and EXCEL workbook. World Health Organization's Rapid Inventory Assessment System (RIAS) and Decision Support System for Industrial Pollution Control. The International Sustainable Systems Research Center's International Vehicle Emissions (IVE) Model, which focuses on control strategies and transportation.

Table 2.2: Summary of low cost tools for air quality management in Sub-Saharan African Countries

Component	Objective	Low Cost Option	Description	Examples
Modelling	The objective for air quality modelling is to support and strengthen national and local air quality estimates and allow source apportionment and estimations of transboundary pollution. This includes quality assured emission data; regional harmonisation of dispersion models and quality assured topographical and meteorological input data for more advanced models.	Simple Dispersion Models	A dispersion model estimates concentration levels at any point in space and, depending on the availability of meteorological information, for any time. Box models illustrate the simplest kind of material balance. To estimate the concentration in a city, air pollution in a rectangular box is considered under the major simplifying assumptions. A Gaussian dispersion model is normally used for considering a point source such as a factory smoke stack. It attempts to compute the downwind concentration resulting from the point source. An airshed model, rather than tracking the plumes of contaminants from point, line and area sources, divides the whole area into a grid of cells, and models what happens as contaminants are moved by the wind from one cell to the next. Airshed models can also take account of chemical transformations that occur in the atmosphere.	The USEPA´s AERMOD Modelling System uses a Gaussian dispersion model. More advanced dispersion and airshed models require more detailed emission data in order to give a precise and representative estimate for the area under consideration. More advanced models currently available include: The Air Pollution Model (TAPM) CALPUFF (Puff model) Urban Airshed Model variable grid (UAM-V) CALGRID Models III photochemical-aerosol modelling system.

Table 2.2: Summary of low cost tools for air quality management in Sub-Saharan African Countries

Component	Objective	Low Cost Option	Description	Examples
Modelling	The objective for air quality modelling is to support and strengthen national and local air quality estimates and allow source apportionment and estimations of transboundary pollution. This includes quality assured emission data; regional harmonisation of dispersion models and quality assured topographical and meteorological input data for more advanced models.	Source Apportionment	Source apportionment (SA) is the determination of the contribution (fraction, percentage or portion) of air pollution sources at a location of interest. A source-oriented approach to SA starts from an emissions inventory and uses dispersion models in the form of chemical transport models (CTMs) to estimate the contribution of each source at a receptor location. A receptor-oriented approach to SA uses mathematical or statistical procedures to compare the profiles of gases and particles (chemical and physical characteristics) at sources and receptors in a given area to estimate the presence and fraction of source contributions at receptor locations.	Comprehensive Air quality Model with eXtension (CAMx) is a publicly available model for integrated assessment of gaseous and particulate air pollution.

Table 2.2: Summary of low cost tools for air quality management in Sub-Saharan African Countries

Component	Objective	Low Cost Option	Description	Examples
Monitoring	The objective for monitoring air pollutants is to establish and/or strengthen national and local air quality monitoring programmes. These include: Representative coverage of outdoor air quality monitoring systems; Periodic review of air quality monitoring issues; Production of baseline data; Satisfactory maintenance of monitoring systems and procuring spare parts; Obtaining data of known quality and their wide dissemination; Focus on quality control and quality assurance of monitoring programmes; Close collaboration among different monitoring agencies; Use of standard operating procedures for monitoring, for data analysis and presentation;	Rapid Air Quality Monitoring Techniques	Major air quality monitoring methods exist include: Passive/diffusive sampling: a sample integrated over exposure time is collected without the use of power supply. Active sampling: a sample integrated over exposure time is collected by pumping the pollutant to the sampler. Automated monitoring: the sample is analysed on-line and in real-time.	Passive/diffuse samplers include the tube and badge type samplers mainly used for the detection of SO_2, NO_2, O_3 and CO. The Radiello Diffusive Sampling System used to measure O_3, NO_2, SO_2, volatile organic compounds (VOC's), hydrogen fluoride (HF), hydrogen chloride (HCl), benzene-toluene-xylenes (BTX), and aldehydes. The High Volume Sampler is an active sampling device for TSP and PM_{10}. The MiniVol Portable Air Sampler is an automated monitoring device that samples ambient air for PM (TSP, PM_{10}, $PM_{2.5}$) and/or non-reactive gases (CO, NO_x) simultaneously.

Component	Objective	Low Cost Option	Description	Examples
Monitoring	Harmonisation of monitoring networks and devices; Monitoring of transboundary air pollution: Monitoring of air quality in urban and peri-urban areas; Hotspot monitoring.	Rapid Air Quality Monitoring Techniques		The DustTRAK™ Aerosol Monitor is a portable, automated (i.e. battery-operated) laser photometer with real-time mass concentration readout and data logging capability. The monitor provides reliable exposure assessment by measuring particle concentrations corresponding to respirable size ($PM_{4.0}$), PM_{10}, $PM_{2.5}$ or $PM_{1.0}$ size fractions.

Table 2.2: Summary of low cost tools for air quality management in Sub-Saharan African Countries

Component	Objective	Low Cost Option	Description	Examples
Health and Environmental Assessment	The objective for health and environmental assessment is to establish and/or strengthen national and local programmes which monitor the health and environmental impact of air pollution in a harmonised way. This includes: Undertaking long-term studies of health and environmental impacts due to air pollution; Strengthening institutional capability; Assessing of health, environmental and economic impacts of air quality; Augmenting and disseminating information on health and environmental impacts; and Ensuring spatial and time representativity of monitoring sites for actual exposure of humans and the environment.	Rapid Epidemiological Assessment Studies	Rapid epidemiological assessment methods include: Use of the WHO environmental burden of disease approach and applying known exposure-response relationships for air pollution impacts to estimate mortality and morbidity. This approach requires knowledge of exposures (air pollutant concentrations and durations). Use of the SIM/Air model to estimate the health impacts on the basis of modelled emissions, simulated concentrations and known exposure-response relationships. Undertaking elementary time-series studies of mortality and morbidity over a time period and correlating health impacts with air pollutant concentrations over the same time period. Undertaking elementary cross-sectional studies of the prevalence of health impacts at high, medium and low exposures and correlating them with corresponding air pollutant concentrations considering confounding variables.	The WHO has estimated the global burden of disease due to environmental factors – outdoor air pollution, indoor air pollution, lead, climate change and estimated the corresponding DALYs. Similar estimations were made for each country. The SIM/Air model uses the WHO exposure-response relationships to estimate the number of premature deaths, incidence of diseases. The model has been applied in Hyderabad, India. Time-series studies have been performed in many developed and some developing countries. Cross-sectional studies have been performed in many developed and some developing countries.

Component	Objective	Low Cost Option	Description	Examples
Health and Environmental Assessment		Rapid Environmental Impact Assessment Studies	Rapid Environmental Impact Assessment Studies include: Checklists for assessing the potential environmental impact of industries and power plants, especially on agriculture, protected sites, forests and biodiversity.	Such checklists are being used by Asian Development Bank to categorize the environmental hazard of new projects for chemical-based industrial facilities, mining industries, power plants, roads and highways, and urban development.
			Estimations of the potential threat of O_3 pollution to reducing agricultural crop yields.	The Council for Scientific and Industrial Research has developed a dispersion model for such estimates and applied it to estimate O_3 concentrations and their potential impact on crop yield in Southern African Development Community countries.

Table 2.3: Summary of low cost policy instruments for air quality management in Sub-Saharan African Countries

Component	Objective	Low Cost Option	Description
Policies	The overall objective of policy instruments is to include and/or strengthen the concept of air quality management in relevant policies and legislation of SSA cities and countries.		
Industry	To implement strategies to reduce urban industrial emissions,	Ban the import of obsolete technologies from developed countries.	Technologies imported in developing countries should follow the same state-of-the-art technology in developed countries in order to avoid health and environmental impacts that will be more costly to sort out once the technology is installed.
		Set limits on the sulphur content of imported coal.	Sulphur content of imported coal should be below 1 per cent. A low sulphur content in fuels reduces SO_2 and sulphate emissions. The sulphur content of coal does not influence the price on the world market
		Desulphurisation of the flue gases	Flue gas desulphurisation in scrubbers is the most cost-effective methods to reduce SO_2 emissions in existing power plants and industrial boilers. The polluter pays principle would mean that the owner of the facility would have to cover the costs.
		Use of two-stage combustion; flue gas recirculation; reducing combustion preheat temperature and low excess air to reduce NO_x emissions.	This is a cost-effective method to reduce NO_x emissions in existing gas- or oil-fired plants. This is essentially a change to operating procedures. The polluter pays principle also applies.

Table 2.3: Summary of low cost policy instruments for air quality management in Sub-Saharan African Countries

Component	Objective	Low Cost Option	Description
Industry		Increased energy efficiency in production to reduce overall energy demand leading to lower fuel consumption and lower emissions.	Enhanced energy efficiency leads to better combustions and consequently lower emissions of gaseous air pollutants.
Transport	To implement strategies to reduce urban motor vehicle emissions.	Traffic management	Traffic management measures include computerised traffic light control, network and junction design, parking controls, reducing the supply of space allocated to car parks, speed limits, avoiding obstacles leading to acceleration- and deceleration driving, restricted access for non-essential traffic, bus priority lanes, pedestrian areas and cycling facilities.
		Regulation and control of public bus transport	Use of efficient and comfortable public transport systems can help reduce transport emissions by reducing use of private vehicles. High standards of quality of service need to be implemented.
		Segregated lanes	Segregated lanes can help smooth the traffic flow thus reducing emissions.
		Non-motorized transport (NMT)	NMT is cycling and walking and serves to reduce short-distance car trips which are most polluting. Segregated lanes for motorized transport and NMT are necessary.

Table 2.3: Summary of low cost policy instruments for air quality management in Sub-Saharan African Countries

Component	Objective	Low Cost Option	Description
Transport		Ban the import of obsolete vehicles and phase-out old vehicles still circulation.	Many vehicle fleets in SSA cities are older than 14 years. Obsolete vehicles which would not be licensed anymore in their countries of origin emit 10 times more air pollutants than newer vehicles. A low cost option is to not allow the import of obsolete vehicles and phase-out old vehicles already in circulation.
		Physical restraint.	Physical restraints on vehicle use may take the form of limiting use of vehicles on specific days or in specific areas provided public transport facilities exist.
		Parking policies	Parking policies including Park and Ride Systems are likely to reduce both congestion and the demand for individual motorized transport. Effective enforcement of parking restrictions is necessary.
		Road pricing	Tolls on roads and motorways and congestion charges for the access to urban areas help limit car movement provided viable alternatives exist and underpricing is avoided.
		Use of low sulphur fuels in vehicles	The use of low sulphur fuels in vehicles, particularly diesel-driven ones reduces the emission of ultra fine sulphates which are a serious threat to human health due to their carcinogenic properties.

Table 2.3: Summary of low cost policy instruments for air quality management in Sub-Saharan African Countries

Component	Objective	Low Cost Option	Description
Transport		Ban of the import of obsolete vehicles and phase-out of such vehicles still circulation in SSA countries	Many vehicle fleets in cities of SSA are over-aged, the vehicles being older than 14 years. Obsolete vehicles which would not be licensed any more in their countries of origin emit 10 times more air pollutants than newer vehicles. A low cost option is to not allow the import of over-aged vehicles and phase-out obsolete vehicles imported before,
Area	To implement strategies to reduce urban emissions from areas sources such as forest fires, burning of biomass and open burning of waste.	Ban deliberate open burning in urban areas and at municipal waste deposits.	A ban of open burning in urban areas helps reduce pollutant emissions. A collection, expert deposition and/or treatment must exist in order to enforce the ban.
		Burn municipal and industrial hazardous wastes in existing cement plants at high temperatures.	Hazardous wastes must be treated before deposition of their residues. Municipal waste incinerators are expensive due to the high temperatures of incineration needed. Cement plants use incinerating temperatures high enough to burn most hazardous wastes and produce non-hazardous ashes and residues.
		Collection and use of used tyres as fuel in tar and lime production facilities if they exist or processed in cement kilns.	Open burning of used tyres in urban areas and on waste deposits leads to high emissions of PM and should therefore be avoided. Their incineration in tar and lime production facilities or cement kiln avoids this problem.

Table 2.3: Summary of low cost policy instruments for air quality management in Sub-Saharan African Countries

Component	Objective	Low Cost Option	Description
All sources		Using WHO air quality guidelines to set air quality standards.	The WHO air quality guidelines AQG) can be utilized for setting air quality standards (AQS) in a country. WHO AQG exists for about 80 pollutants. They can be used to set AQS in a stepwise procedure corresponding to the environmental, technological, cultural and financial situation in SSA countries.
		Use of a simple integrated model for air quality management.	The Simple Integrated Model for Better Air Quality (SIM-AIR) is a relatively new interactive model to examine emissions, ambient air quality and health.
Transboundary	To implement strategies to reduce emissions which contribute to: regional haze from forest fires, atmospheric brown cloud (ABC), acid deposition, regional dust and importation of hazardous waste.	Use of low-sulphur fossil fuels (low sulphur coal and oil, and natural gas).	Combustion of low sulphur fuels in industries and vehicles reduces the emission of ultra fine sulphates which are a serious threat to human health.
		Use of low excess air NO_x burners in industries can help to reduce NO_x emissions during combustion	This is a cost-effective method to reduce NO_x emissions in existing gas- or oil-fired plants and is essentially a change to operating procedures. The polluter pays principle should always apply but in the case of transboundary pollution needs agreements among countries are needed.
		Use of flue gas desulphurisation and denitrification to remove the pollutants from flue gas.	New plants to be installed in SSA countries should employ state of the art technology as in developed countries with respect to desulphurisation and denitrification in order to avoid cost-intensive *a posteriori* measures or be forced to accept human health and environmental impacts.

Table 2.3: Summary of low cost policy instruments for air quality management in Sub-Saharan African Countries

Component	Objective	Low Cost Option	Description
		Ban the importation of hazardous chemicals and hazardous wastes by implementing Amendment Decision III/1 to the Basel Convention and the Bamako Convention.	A ban on the importation of hazardous chemicals and hazardous wastes from developed to SSA countries avoids the 'social dumping' of hazardous materials which cannot be properly treated in developing countries. Thus, all SSA countries should adopt Amendment Decision III/1 to the Basel convention and the Bamako convention.
		For vehicle emission reduction, low sulphur fuels and NO_x control devices can be applied.	The use of low sulphur fuels in vehicles, particularly diesel vehicles reduces the emission of ultra fine sulphates. NO_x control devices (catalysts) reduce NO_x emissions and limits O_3 chemical conversion. A prerequisite for effective NO_x control is the supply of fuels of appropriate quality and existence of an enforced inspection and maintenance system.

Table 2.3: Summary of low cost policy instruments for air quality management in Sub-Saharan African Countries

Component	Objective	Low Cost Option	Description
Climate Change	To implement strategies to reduce greenhouse gas emissions which contribute to global climate change	Implement measures to achieve co-benefits in the reduction of urban air pollutants and greenhouse gas (GHG) emissions	Many measures of air pollution reduction also reduce GHG emissions. Such measures include cleaner production technologies, cleaner fuels and vehicles, and demand management of goods and services.
		Use the Clean Development Mechanism (CDM) as a measure to implement co-benefit measures	The use of the CDM can lead to increased energy efficiency and conservation; transfer of technologies and financial resources; local environmental and human health benefits. Subsequent benefits will include sustainable energy production; private and public sector capacity development; and poverty alleviation and equity realisation through income and employment generation.

Chapter 3

Emissions

3.1 Objective

The objective for emission reduction is to include and/or strengthen enforceable, affordable, sustainable and highly effective measures to assess and reduce emissions. These include:

- short-term strategies to reduce emissions to adequately address the overall problem;
- use of end-of-pipe and best available control technology solutions to prevent pollution; and
- effective measures to reduce air pollution which are fully coordinated with other measures.

3.2 Situation

Measures which have been taken to reduce air pollutant emissions include the removal of lead from motor vehicle fuel. Lead has been phased-out in all SSA countries and is therefore no longer a major problem if no other sources of lead such as lead smelters exist. Sulphur content in diesel is a major source of fine particles (sulphates). Diesel sulphur levels in SSA countries vary between 500 ppm (Botswana, South Africa, and Swaziland) and 10,000 ppm (Congo-Brazzaville, Ethiopia and Kenya) with many other countries having levels of 5,000 ppm. Three SSA countries (Gabon, Mozambique, and Zambia) have sulphur content levels above 5,000 ppm but below 10,000 ppm and two countries limit the sulphur content to 3,500 ppm (Congo-Kinshasa) and 2,500 ppm (Mauritius). In order to reduce the emission of sulphates from diesel vehicles, the European Union (EU) and the United States (US) have recently reduced sulphur content levels to 50 ppm. Compared to this limit, diesel sulphur content in SSA countries are high. Sulphur content in fuels need to be reduced in order to reduce sulphates emissions. There is a growing need to identify the sources of polluting emissions and take effective measures to protect human health and the environment.

The majority of SSA countries have not set emission standards for mobile and stationary sources. The lack of emission standards together with the absence of inspection and maintenance (I&M) facilities mean that it is not possible to control the performance of secondhand cars and other imported vehicles. Standards for imported vehicles can be achieved in a cost-effective way if the importer of vehicles is requested to provide a proof of compliance with emission standards. The requirement of catalytic converters in second-hand cars can also be fulfilled in a relatively cost-effective way. However, vehicles equipped with catalytic converters loose the cleaning capacity after two years of operation if not maintained. This requires the establishment of I&M facililties which can only be realised in SSA countries with substantial support from donor agencies.

Five countries (Botswana, Burkina Faso, Kenya, Madagascar, and Uganda) have set or proposed emission standards for mobile sources, either petrol- or diesel-driven or both. These standards relate to emissions of CO, CO_2, NO_x, HCs and VOCs. Emission standards for stationary source exist or are being set in five countries (Botswana, Burkina Faso, Kenya and Mauritius). Mauritius has developed a comprehensive set of emission standards for several source types and a number of pollutants.

Emission Standards in Sub-Saharan African Countries

Burkina Faso has set emission standards for emissions of CO, NOx, HC and VOC for mobile sources. It has also adopted emission standards for power plants, industrial plants, cement factories and brick kilns. Another example of the control of diesel- and petrol-driven vehicles is the emission standards of Madagascar.

In Mauritius emission standards are set for stationary sources of all industries, power plants and industrial boilers. They are based on best available technology locally available. Emission standards are set for

- PM_{10} emitted from all industries and power plants;
- SO_2 emitted from thermal power stations (new and existing) and industrial boilers;
- NO_x applicable to all industries and power plants;
- CO emitted from all types of plants;
- VOCs emitted from all types of plants.

These emission standards follow World Bank recommendations.

Mauritius has also regulated stack design and operation of boilers with respect to efficient combustion and compliance with emission standards. Mauritius' legislation also deals with cleaner production and efficient use of energy.

Source: Schwela (2007)

Some countries such as Mozambique, Senegal and Uganda lack a waste management system comprising of recycling, reducing, incinerating and depositing wastes. Some but not all waste is eventually transported to deposits where it is sometimes incinerated or incinerates itself (i.e. due to high temperatures the waste self-combusts). As a consequence, uncontrolled burning of wastes in cities is common practice. This problem requires urgent attention because emissions from uncontrolled burning of wastes including household wastes, tyres, and electrical devices emit not only the key pollutants but also VOCs, PAHs, dioxins and furans. Some of these pollutants are carcinogenic and/or highly toxic. In order to protect public health, open burning of wastes should be prohibited. A corresponding law can, however, only be enforced if a viable waste management system is operational.

Emissions inventories for urban areas do not yet exist in SSA countries with the possible exception of South Africa. The APINA programme has initiated the development of emissions inventories on a regional basis in some SADC countries such as Mozambique, using the Global Atmospheric Pollution Forum (GAPF) approach discussed below (GAPF, 2007). In contrast, the country emissions of CO_2 have been estimated by the Energy Information Administration (EIA) between 1980 and 2005 (EIA, 2007). The total CO_2 emissions for all SSA countries have practically doubled between 1980 and 2005. Individual countries such as Angola and Sudan show much stronger variations. In Angola CO_2 emissions increased five-fold between

1980 and 2005 while in the Sudan the increase during the same time was threefold (see Table 3.1). Most CO_2 emissions are from South Africa and Nigeria. SSA account for approximately 65 per cent of all African CO_2 emissions.

Table 3.1: CO_2 emissions [millions of metric tons] between 1980 and 2005 in SSA countries

Country	1980	1985	1990	1995	2000	2005
Angola	3.59	4.59	7.15	12.11	13.01	20.39
Benin	0.42	0.47	0.59	0.95	1.64	2.27
Botswana	1.26	1.45	2.68	3.44	4.33	3.92
Burkina Faso	0.40	0.43	0.49	0.68	1.05	1.17
Burundi	0.10	0.15	0.26	0.36	0.37	0.41
Cameroon	2.31	6.61	3.43	7.51	6.81	6.81
Cape Verde	0.33	0.18	0.10	0.11	0.17	0.28
Central African Republic	0.15	0.21	0.25	0.29	0.32	0.34
Chad	0.29	0.13	0.33	0.17	0.19	0.19
Comoros	0.04	0.04	0.07	0.08	0.10	0.10
Congo (Brazzaville)	0.78	0.95	1.13	3.10	3.01	5.31
Congo (Kinshasa)	3.42	3.51	3.64	3.70	2.69	2.37
Cote d'Ivoire	4.23	4.26	4.51	4.50	7.32	6.42
Djibouti	1.65	0.79	1.72	1.80	1.84	1.95
Equatorial Guinea	0.06	0.08	0.12	1.06	2.05	4.87
Eritrea	- -	- -	- -	1.06	0.64	0.78
Ethiopia	1.62	2.62	2.97	2.36	3.43	4.37
Gabon	4.77	5.43	5.71	5.47	5.06	4.95
Gambia, The	0.16	0.17	0.19	0.22	0.26	0.30
Ghana	2.26	1.98	2.80	3.96	5.28	6.67
Guinea	0.92	0.75	1.47	1.22	1.29	1.34
Guinea-Bissau	0.09	0.12	0.26	0.32	0.35	0.38
Kenya	5.99	5.55	6.66	7.13	8.65	9.88
Lesotho	0.09	0.15	0.15	0.18	0.21	0.21
Liberia	2.05	1.62	0.58	0.38	0.44	0.53
Madagascar	1.29	1.29	0.96	1.28	1.80	2.54
Malawi	0.60	0.48	0.53	0.73	0.75	0.86
Mali	0.42	0.49	0.47	0.52	0.56	0.66
Mauritania	0.56	0.84	0.94	3.10	3.23	2.63
Mauritius	0.92	0.95	1.92	2.42	3.47	4.01
Mozambique	2.71	2.31	1.19	1.21	1.27	2.30
Namibia	- -	- -	2.33	1.28	1.80	2.67
Niger	0.61	0.81	1.09	1.15	1.16	1.23
Nigeria	68.50	61.91	81.41	99.84	80.42	105.19
Rwanda	0.15	0.49	0.70	0.70	0.76	0.78
Sao Tomé e Principe	0.03	0.03	0.07	0.08	0.09	0.10
Senegal	2.57	2.83	2.56	3.83	4.40	5.49
Seychelles	0.22	0.31	0.45	0.52	0.58	0.92
Sierra Leone	0.70	0.74	1.06	0.84	0.91	1.18
Somalia	0.99	1.33	0.98	0.58	0.72	0.75

Table 3.1: CO_2 emissions [millions of metric tons] between 1980 and 2005 in SSA countries (cont/)

Country	1980	1985	1990	1995	2000	2005
South Africa	234.19	298.81	295.48	344.20	383.42	423.81
Sudan	3.26	3.67	3.86	3.98	6.47	10.79
Swaziland	0.60	0.69	0.75	0.90	1.26	1.14
Tanzania	2.04	2.19	2.78	2.44	2.70	3.97
Togo	0.58	0.62	0.58	0.62	1.40	2.38
Uganda	0.75	0.59	0.84	1.02	1.26	1.62
Zambia	3.70	2.90	2.72	1.91	1.88	2.45
Zimbabwe	8.87	9.56	15.02	14.73	13.28	11.78
SSA	**371.26**	**436.06**	**465.95**	**550.03**	**584.11**	**675.49**
Africa	**534.47**	**641.15**	**718.13**	**817.88**	**881.24**	**1,042.92**
SSA/Africa [%]	**69.5**	**68.0**	**64.9**	**67.3**	**66.3**	**64.8**

Source: EIA (2007)

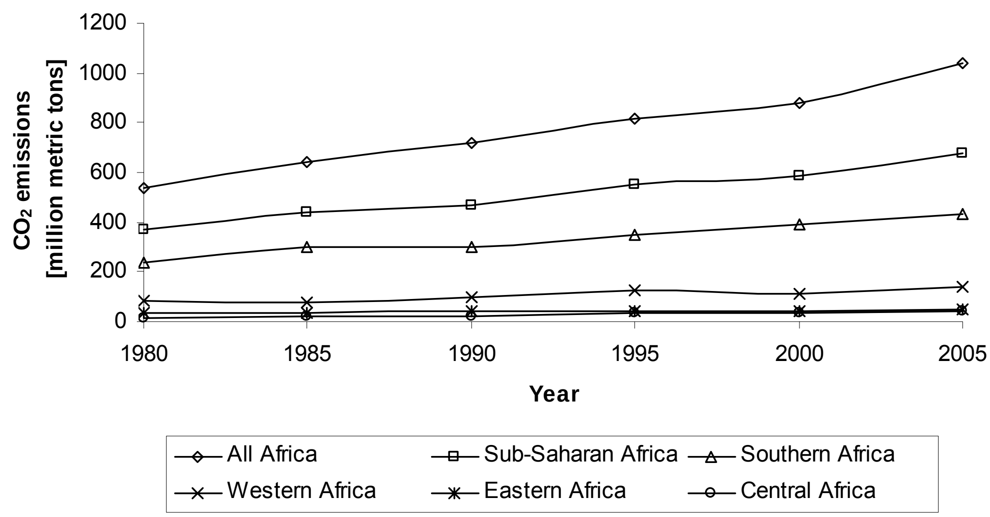


Figure 3.1 CO_2 emissions in regions of Sub-Saharan Africa (1980-2005)
Source: EIA (2007)

3.3 Emissions Inventories

Air pollutant emissions inventories are the basic building blocks of air quality modelling and an integral part of AQM strategies. In Europe and North America there is official national reporting of emissions inventories for a number of pollutants. However, in SSA routine estimation and reporting of emission estimates of sufficient quality is either absent or only available in a few countries. If estimates exist they are often unreliable, contradictory and/or unrealistic. In most developing countries the capacity to undertake reliable estimations is generally lacking. Without detailed and reliable emissions inventories, there is little opportunity to develop strategic plans to deal with air pollution and to monitor the effectiveness of such plans. In many cases the sources of pollution are obvious and are already being addressed. However, the level of emission reduction achieved or achievable by these measures remains poorly understood due to the lack of high quality emission factors and inventory techniques.

Emission Inventory

An emissions inventory is generally defined as a comprehensive listing of sources and an estimation of the magnitude of air pollutant emissions in a geographic area during a specific time period. It can have different geographical scales ranging from global to individual plant level emissions. An inventory can be compiled at the national level, or emissions at the national level can be the sum of emissions compiled at smaller geographical scales (e.g. county, municipality or even facility level). An inventory can be given for a single year only, but inventories for more years (time-series) are needed for most applications.

Emissions inventories should be annually compiled and updated. An emissions inventory can be used in a variety of ways as part of an integrated AQM programme. It can be used to:

- estimate the magnitude of local, regional or national emissions;
- evaluate emissions tendencies;
- serve as input in air quality models;
- assure compliance with regulatory/legal decisions (emission standards) and actions relating to emissions and/or air quality;
- estimate the impact of new sources of pollution (e.g. planning new industrial plants or changing processes in existing plants or allowing the use of different types of vehicles);
- support the setting of emission fees for sources;
- establish emission trading programmes;
- help revise current air quality regulations, policies and strategies; and
- initiate strategies and regulations for AQM.

Emissions inventories can be approached in two ways: top-down or bottom-up. The key decision on which approach to take is generally based on available resources. In a **top-down approach** national- or regional-level emission estimates allocated to state or county based on surrogate parameters such as population, employment, energy consumption, resource use and growth in the number of motor vehicles. Such an approach requires modest resources. It is used when local data are not available, cost to gather local data is prohibitive, and the end use of data does not justify the cost to collect it. A top-down approach is typically used to inventory area sources.

In contrast, a **bottom-up approach** collects source-specific information on individual sources, processes, activities and their levels, and estimates emission factors. This approach is usually used to inventory major sources. The results from a bottom-up approach provide more accurate estimates than the top-down approach. However, this approach requires more financial resources, depending on the requested level of detail and accuracy.

An emissions inventory addresses all relevant sources. It can often be labour-intensive to collect data, in particular when more sophisticated methods are applied. In this situation priority should be given to the key sources. Key sources are those that have a significant influence on the absolute level of emissions, the trend in emissions, or the reduction of uncertainty of estimated emissions. A key source is also determined by the toxicities of emitted compounds. For example, for two sources with equal mass emissions of compounds of different toxicity, the source which emits the more toxic compound has a higher relevance in a list of sources than the one which emits the less toxic compound. In turn, a source with a low emission of a highly toxic compound may be more relevant than a source with a high emission of a much less toxic compound. The consideration of key sources should be the priority for countries during inventory resource allocation for data collection, compilation, quality assurance/quality control and reporting.

Rapid Emissions Inventory

The GAPF has produced a manual and EXCEL workbook for a rapid emission inventory (GAPF, 2007). The **GAPF Emissions Inventory Manual** provides a simplified and user-friendly framework for emissions inventory preparation which is suitable for use in different developing and rapidly industrialising countries. It is compatible with other major international emissions inventory initiatives.

Inventory methods are provided for estimating emissions from the following sources: fuel combustion and transformation; fugitive emissions from fuels; industrial process emissions (non-combustion); emissions from solvent and other product use; emissions from agriculture (including savannah fires); emissions from other vegetation fires and forestry; and emissions SO_2, NO_x, CO, non-methane volatile organic compounds (NMVOC), ammonia (NH_3) and PM_{10} and $PM_{2.5}$. The EXCEL workbook serves as a tool in preparing emissions inventories.

Rapid Inventory Assessment System

In 1993 WHO published a rapid inventory guide, part one of which discusses rapid inventory techniques in environmental pollution and part two describes approaches for consideration in formulating environmental control strategies (WHO, 1993). The emissions inventory methodology used in this publication has been used in numerous countries. The technique, generally referred to as **Rapid Inventory Assessment System (RIAS)**, is frequently used as part of AQM training courses. A computer program called "**Decision Support System for Industrial Pollution Control**" has also been developed and is available on CD-ROM (WHO, 1997; 1998). A Tutor's Guide is also available (WHO, 1996a), which addresses workshop organisation, course agenda, and provides transparency charts and lecture notes, as well as the training of participants through the solution of selected environmental problems (WHO, 1996b). Moreover, it offers evaluation questionnaires to be used before and after the workshop. For motor vehicle emission estimates, a Teacher's Guide gives practicable examples of the estimation methods (WHO, 1996c).

For a country or region with very limited resources the use of rapid assessment techniques can provide a good indication of the magnitude and type of air pollutant emissions as well as identifying some initial control strategies for consideration. RIAS can provide the country with an initial decision support system. This relatively simple and straightforward approach to emissions inventories is based on existing information on a facility's activity, quantity of emissions, application of existing or proposed control equipment and estimations of released pollution load. The RIAS contains various emission factors for both stationary and mobile sources of pollution (WHO, 1993). Many of these factors have since been updated in AP-42 (USEPA, 2004) or in the European CORINAIR (EEA, 2007) and correspond to the implementation of new technologies for stationary and mobile sources. One must therefore use them with caution or substitute them with newer factors. However, for the technologies still in place in many developing countries, the 1993 emission factors may represent reality more closely than the new emission factors developed for modern technologies in developed countries. There are several advantages to the use of the WHO rapid assessment approach which include:

- convenience of use;
- limited time and little resources required;
- effectiveness of alternative control;
- assessment of measures.

International Vehicle Emissions Pollution Program

The International Sustainable Systems Research Center (ISSRC) has developed the **International Vehicle Emissions** (IVE) Model, which focuses on control strategies and transportation. The IVE model predicts how different strategies will affect local emissions, and measures progress in reducing emissions over time. Local air pollutants, greenhouse gases, and toxic pollutants can be estimated with the IVE Model (ISSRC, 2005). Existing US and European models take into account the modern technologies and conditions that exist in most developed countries. These technologies and conditions do not prevail in developing countries. A model applicable for developing countries must consider the local toxic emissions that are needed to fully evaluate the impact of motor vehicles. The IVE Model is designed to have the flexibility needed by developing nations in their efforts to address mobile source air pollutant emissions. Reports on IVE vehicle activities exist for Almaty, Kazakhstan; Beijing, China; Lima, Peru; Mexico City, Mexico; Nairobi, Kenya; Pune, India; Santiago, Chile; Sao Paulo, Brazil; and Shanghai, China. A report on the measurement of in-use passenger vehicles in three urban areas of developing nations describes the gasoline emissions testing results and applications of the IVE model in Mexico City; Sao Paulo; and Nairobi.

More sophisticated but also much more expensive emissions inventory models exist such as the OECD/MAP Project (EEA, 2007; OECD, 1996); the NARSTO third assessment on the current state of emissions inventories for North America (NARSTO, 2006), CORINAIR and USEPA Air CHIEF programme (USEPA, 2007d). The German-Swiss emission calculation system consists of a set of three emission models with a different level of complexity: the Handbook of Emission Factors for Road Transport (HBEFA, 2004a: 2004b); the Computer-aided Instrument for predicting the impact of Traffic measures on Air pollution Reduction (CITAIR) (UBA, 2002: 2007) and the TRansport Emission estimation MODel (TREMOD) (UBA, 2007).

3.4 Implementation in Sub-Saharan Africa

Because of limited resources, measures to develop emissions inventories in cities of SSA should focus on the key pollutants and sources. The scope and extent of emissions inventories in SSA cities may thus be quite different from those envisaged in developed countries.

In order to reduce emissions short-term strategies need to be replaced by medium- and long-term strategies for emissions prevention and reduction. These will define an improved way to address air quality problems in SSA. The prevention of pollution by substitution of fuels and alternative technologies is always less expensive than end-of-pipe pollution reduction, including the costs of health and environmental impacts.

If measures to reduce air pollution are combined with aspects of land use planning and the introduction of public mass transport systems aimed at prevention of pollution, synergies can achieve greater improvements. Positive and negative lessons learnt from experiences in other cities can assist in identifying best practice and optimal solutions.

The compilation of a rapid inventory of emission sources is a good starting point for dispersion estimations of air pollutant concentrations. An emission inventory also allows the verification of source apportionment estimates. Source apportionment can be supported with rapid assessment emissions inventories. A nationally accredited agency can validate and assure the quality of the data collected.

A periodical update (numerical reduction) of emission standards for emitting sources and the implementation of the new standards will bring about reductions in emissions and air pollution provided the emission reduction is not cancelled out by the increase in the number of emitting sources. Regional harmonisation of emission standards helps to fulfil the guiding principle of equity and avoids the importation of obsolete technology.

Economic incentives and disincentives and the examination of the potential for emission reduction (e.g. differentiated fuel taxes) are useful measures for rapid emission reduction. The development of low cost and effective alternative technologies can contribute to the development of SSA countries.

Emissions from mobile sources can only be reduced through a combination of measures. These include: tighter emission standards for new and in-use vehicles; cleaner vehicle technology; cleaner fuels; inspection and maintenance programmes;; integrated regional land use, traffic planning and demand management; public transport and non-motorized transport; renewable energy sources and zero emission technology; economic incentives/taxation; establishment of emission standards for ships and aeroplanes; and innovative alternatives to further reduce emissions.

In order reduce motor vehicle emissions a good starting point would be the setting of fuel specifications for new and imported second-hand vehicles. The implementation includes to

- identify the stakeholders in importation/production, distribution and storage;
- set specifications for new refining technologies;
- address the import of vehicles; and
- raise stakeholder awareness.

Most SSA countries do not employ vehicle inspection and maintenance facilities. Inspection and maintenance of vehicles, even of new ones with catalytic converters, is an issue to be considered in any action plan as it is formulated. Lack of maintenance makes catalytic converters inefficient after a couple of years and the vehicles become more polluting.

Emissions from stationary sources can be reduced through a combination of measures: tighter emission standards; cleaner fuels; emission control technologies and cleaner production; land use planning, zoning and economic restructuring; enhancing enforcement; economic incentives/taxation; and finding innovative alternatives to further reduce emissions.

Emissions from area sources can be reduced through a combination of measures which include: 'greening' of areas (e.g. reforestation); road cleaning and street cleansing; implementation of guidelines for managing construction and waste deposit sites; reduced open burning; enhancing enforcement; finding innovative alternatives to further reduce emissions as well as economic incentives/taxation.

3.5 Summary

Emissions inventories must be as accurate as possible. They should consider all relevant sources of air pollutants and their potential impact on human health and the environment. Emissions inventories should be complete with respect to key sources. The consequences of incomplete or inaccurate emissions inventories are flawed decisions on control measures which do not achieve what they there were intended to achieve. Table 3.3 presents a summary of the low cost rapid emission inventories currently available.

Rapid assessment of emissions is the most cost-effective way to obtain a fairly reliable emissions inventory. It is important to be aware of the uncertainties in the emissions inventory.

Best available control technologies exist for stationary sources and should be applied because preventing emissions at the source is always less expensive that *a posteriori* measures including treatment of health impacts.

For mobile sources cleaner fuels and engines, alternative technologies such as solar-driven or hybrid vehicles, inspection and maintenance programmes and transport and demand management are suitable measures to limit air pollution and GHG emissions.

Table 3.3: Summary of the low cost options for emissions

Objective	Low Cost Option	Description	Examples
The objective for emission reduction is to include and/or strengthen enforceable, affordable, sustainable and highly effective measures to assess and reduce emissions. These include: short-term strategies to reduce emissions to adequately address the overall problem; use of end-of-pipe and best available control technology solutions to prevent pollution; and effective measures to reduce air pollution which are fully coordinated with other measures.	Rapid Emission Inventories	An emissions inventory is generally defined as a comprehensive listing of sources and an estimation of the magnitude of air pollutant emissions in a geographic area during a specific time period. Rapid Emission Inventories provide a simplified and user-friendly framework for emissions inventory preparation. Rapid Emission Inventories are suitable for use in different developing and rapidly industrialising countries and are compatible with other major international emissions inventory initiatives.	Global Atmospheric Pollution Forum's rapid emission inventory manual and EXCEL workbook. World Health Organization's Rapid Inventory Assessment System (RIAS) and Decision Support System for Industrial Pollution Control. The International Sustainable Systems Research Center's International Vehicle Emissions (IVE) Model, which focuses on control strategies and transportation.

Chapter 4

Modelling

4.1 Objective

The objective for air quality modelling is to support and strengthen national and local air quality estimates and allow source apportionment and estimations of transboundary air pollution. A further objective is also to estimate concentrations of pollutants that are difficult or too expensive to monitor. This includes quality assured emission data; regional harmonisation of dispersion models and quality assured topographical and meteorological input data for more advanced models.

4.2 Situation

Air quality modelling is hardly used in the majority of SSA countries with the exception of South Africa. This is due to the lack of quality assured emission data and source apportionment experience.

4.3 Dispersion Model

A dispersion model is a set of mathematical equations used for determining what happens to pollutants emitted in the atmosphere. It simulates the process of atmospheric dispersion, which mixes the pollutant with the existing air. The pollutant is transported by the mean wind and its concentration decreases due to atmospheric turbulence with distance from the source. A dispersion model estimates concentration levels at any point in space and, depending on the availability of meteorological information, for any time. A dispersion model:

- estimates spatial and time distribution of pollutants from different sources;
- allows estimate concentrations from existing and planned sources;
- helps select the most appropriate site for monitoring;
- assesses compliance of concentrations from emissions of planned facilities with air quality guidelines and/or standards (including existent concentrations due to other sources);
- assesses the impact of emissions of a plant which is to undergo a process change;
- determines appropriate stack heights;
- assesses the contribution of individual plants to the overall concentrations;
- assists in the design of ambient air monitoring networks;

- evaluates the impact and efficiency of policy and mitigation strategies (e.g. the effect of emission standards);
- forecasts pollution episodes;
- assesses the risks of and planning for the management of rare events such as accidental hazardous substance releases;
- estimates concentrations of pollutants too difficult or expensive to measure;
- estimates the influence of geophysical factors on dispersion (e.g. terrain elevation, presence of water bodies and land use);
- tracks the originating source of accidental hazardous substance releases;
- replaces monitoring and provides cost and time savings.

Not every dispersion model can address the many processes in the atmosphere that occur during the transport of air pollution. Usually, a model considers part of these phenomena and leaves out others. The selection of a specific model depends on the task that has to be addressed.

Box Models

Box models illustrate the simplest kind of material balance. To estimate the concentration in a city, air pollution in a rectangular box is considered under the following major simplifying assumptions (see Figure 4.1):

- The city is a rectangle with dimensions W (downwind) and L (crosswind), both in units [m]. The box is defined by W·L·H [m^3] where H [m] is called the mixing height.
- The air pollution emission rate of the city is independent of space and time (continuous emission).
- The mass of pollutant emitted from the source remains in the atmosphere. No pollutant leaves or enters through the top of the box, nor through the sides that are parallel to the wind direction.
- No deposition, including gravitational settling or turbulent impaction occurs.
- No material is removed through chemical transformation (destruction rate equals zero).
- Atmospheric turbulence produces complete and spatial uniform mixing of pollutants within the box.
- The turbulence is strong enough in the upwind direction that the pollutant concentrations [mass/volume] from releases of the sources within the box and those due to the pollutant masses entering the box from upwind side are spatially uniform in the box.
- The wind blows with an average (constant) velocity.

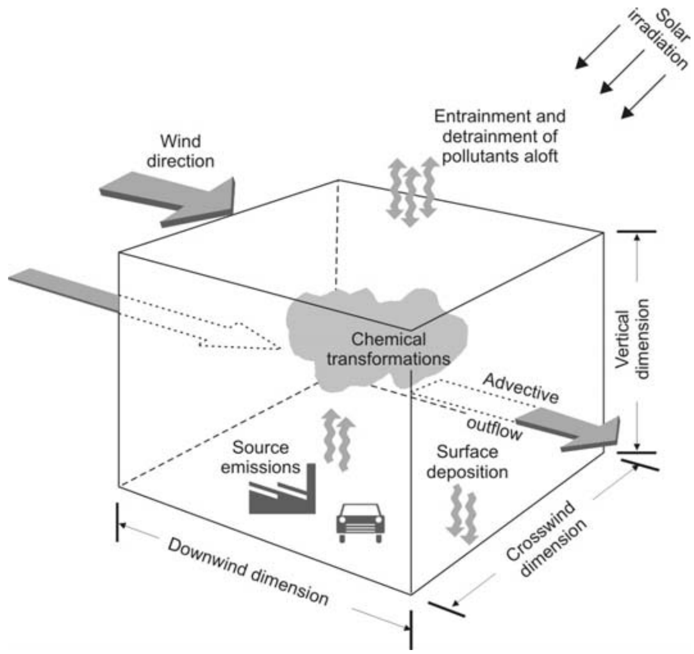


Figure 4.1: The box model

These assumptions lead to a steady state situation and the accumulation rate is zero. All the terms can then be easily quantified and calculated.

Box models have several drawbacks. Firstly, some of the assumptions are unrealistic (e.g. wind speed independent of height or uniformity of air pollutant concentrations throughout the box). Secondly, the model does not distinguish a configuration of a large numbers of small sources emitting pollutants at low elevation (cars, houses, small industry, and open burning) from that of a small number of large sources emitting larger amounts per source at higher elevation (e.g. power plants, smelters and cement plants). Both types of sources are simply added to estimate a value for the emission rate per unit area (q). Of two sources with the same emission rate, the higher elevated one leads to lower ground level concentrations in reality. As there is no way to deal with this drawback, box models are unlikely to give reliable estimates, except perhaps under very special circumstances.

Nevertheless, knowledge of box models as an elementary approach assists in appreciating the complexity of dispersion processes.

Gaussian Dispersion Models

The Gaussian model is based on the following assumptions:

- continuous emissions;
- conservation of mass;
- steady-state meteorological conditions for the travel time of pollutant from source to the receptor;
- concentration profiles in the crosswind direction and in the vertical direction (both perpendicular to the path of transport) are represented by Gaussian or normal distributions (see Figure 4.2).

A Gaussian model starts from the solution of the basic equations for transport and diffusion in the atmosphere assuming stationarity in time and complete homogeneity in space. A Gaussian dispersion model is normally used for considering a point source such as a factory smoke stack. It attempts to compute the downwind concentration resulting from the point source. The origin of the coordinate system is placed at the base of the stack, with the x axis aligned in the downwind direction. The contaminated gas stream, which is normally called "plume", is shown rising from the smokestack and then levelling off to travel in the x direction and spreading in the y and z directions as it travels.

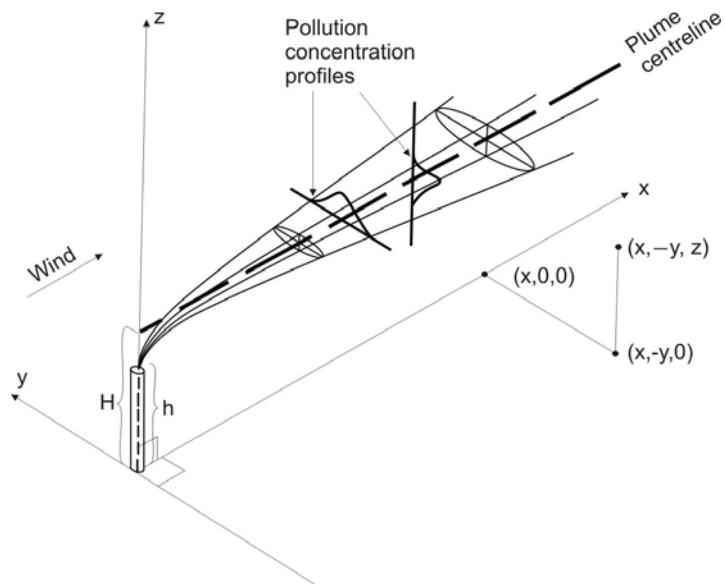


Figure 4.2: The Gaussian plume model

Source: Turner (1994)

The plume normally rises to a considerable height above the stack because it is emitted at a temperature higher than that of ambient air and with a vertical velocity component. It should be kept in mind that the Gaussian plume approach tries to calculate only the average values without making any statement about instantaneous values. The results obtained by Gaussian plume calculations should be considered only as averages over periods of at least 10 minutes, and preferably one-half to one hour.

The Gaussian plume model so far allows one to estimate the concentration at a receptor point due to a single emission source for a specific meteorology. In this form, they are frequently used to estimate maximum concentrations to be expected from single isolated sources.

Gaussian plume models are also applied to estimate multi-source urban concentrations. The procedure is to estimate the concentration at various locations for each of the point, area and line sources in the city for each meteorological condition and then sum up over all sources, all wind directions, all wind speeds, and all stability classes, weighted by the frequency of their occurrence.

The USEPA **AERMOD Modelling System** uses a Gaussian dispersion model. It is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain (USEPA, 2005).

In simple Gaussian models pollutants are assumed to remain in the atmosphere forever. No pollutant really behaves that way as they all rather have natural removal mechanisms. Pollutants such as HCs, NO_x, and oxidants all undergo reactions in the atmosphere. The reaction times may also be comparable to travel time across a city, therefore, the simple box and Gaussian dispersion model, as presented so far, predict values much higher than the observed values. There are ways to modify the calculations through correction factors.

Standard Gaussian models cannot handle very well all the sources of emissions in a whole urban area. An **airshed model**, rather than tracking the plumes of contaminants from point, line and area sources, divides the whole area into a grid of cells, and models what happens as contaminants are moved by the wind from one cell to the next. Airshed models can also take account of chemical transformations that occur in the atmosphere. Table 4.1 presents some advanced dispersion models and airshed models that are currently available.

The data inputs to air quality models mainly consist of emission and meteorological data. The modelling parameters include:

- emission sources including their location, rates of emitting and other characteristics;
- receptor locations;
- characteristics such as deposition rates if deposition is also considered;
- meteorological specifications;
- output options that will specify what kind of values are required (e.g. average
- concentrations in space and time at each grid point); and
- need to be provided in a format adapted to the input interface of the model.

Emission data are a crucial input for any dispersion model. They should be accurate, precise and representative for the area to be considered. No dispersion model can compensate for unreliable emission data. Conclusions and control actions derived from simulated concentrations based on unreliable or wrong emission data may be completely misleading and even useless.

Most air quality dispersion models described in the USEPA *Guideline on Air Quality Models* (FR, 2005; USEPA, 2006) are Gaussian models requiring input data which represents the conditions at the sites of interest. The input data is also required to follow a prescribed data content and format. As a rule, dispersion models such as AERMOD require five meteorological inputs. These are: wind speed and direction, vertical mixing, temperature and atmospheric moisture. Some slightly more detailed models (e.g. CALPUFF) may also need inputs such as dew point, cloud cover, cloud layer(s), ceiling height, visibility and precipitation. For air quality modelling purposes, meteorological grid models are used in conjunction with chemical interaction models to provide gridded output of chemical species or pollutant data. The meteorological parameters are calculated at distinct spatially equidistant points over an area of interest which is called a grid.

Table 4.1: Selected advanced dispersion and airshed models

The Air Pollution Model (TAPM) www.dar.csiro.au/tapm	o simulates three-dimensional meteorology and pollution dispersion o long-term simulations can be carried out on a PC o simulates dispersion from point, line and area sources o allows for plume rise and building wake effects o allows for wet and dry deposition o allows for chemical transformation
CALPUFF (puff model) www.src.com/calpuff/calpuff1.htm	o guideline model for regulatory applications involving long-range transport (FR, 2005; USEPA, 2005; TRC, 2008) o able to simulate the effects of time- and space-varying meteorological conditions on pollutant transport o accounts for dry deposition and dispersion over a variety of spatially varying surfaces o accounts for plume fumigation, low wind-speed dispersion, pollutant transformation and wet removal o can be downloaded free of charge
Urban Airshed Model variable grid (UAM-V) www.epa.gov/scram001 www.uamv.com/	o most common and advanced airshed model o numerous modules and a complex structure o can be downloaded free of charge
CALGRID www.arb.ca.gov/eos/soft.html#calgrid	o more user-friendly model linked to CALPUFF and CALMET o needs a focused effort to obtain the appropriate emissions inventory and meteorological files o can be downloaded free of charge
Models III photochemical-aerosol modelling system www.epa.gov/asmdnerl/models3/cmaq.html	o complex, multi-scale modelling system o comprises an emissions inventory, prognostic meteorological modelling, and chemical transport-transformation modelling o models the processes of pollutant transport, chemical transformation and wet and dry deposition for a variety of primary and secondary aerosol and gaseous species

Source: Ministry for the Environment (2004)

4.4 Source Apportionment

Source apportionment (SA) is the determination of the contribution (fraction, percentage or portion) of air pollution sources at a location of interest. Air pollution originates from sources such as industries, power plants, cars, buses, trucks, boats, windblown dust and open burning. The development of effective control strategies to protect public health and the environment from exposure to air pollution requires knowledge of emission sources that contribute to the pollutant concentrations at the receptor. Pollutant concentrations are obtained from ambient air samples collected at a receptor location.

Two different approaches are used in source apportionment: The source-oriented approach and the receptor-oriented approach. The **source-oriented approach** starts from an emissions inventory and uses dispersion models as discussed above in the form of chemical transport models (CTMs) to estimate the contribution of each source at a receptor location. Transport calculations use emission and source characteristics (stack height, exit velocity of stack gas, pollutant concentrations in exhaust gas) and known meteorological parameters (wind speeds, wind directions, temperature, mixing heights and atmospheric stability classes) to predict pollutant concentrations at specific receptor air monitoring locations. This type of model can be validated by comparison of the predicted spatial and temporal distribution of pollutant concentrations with measured concentrations.

The **Comprehensive Air quality Model with eXtension** is an example of CTM (CAMx; ENVIRON, 2004). It is a publicly available model for integrated assessment of gaseous and particulate air pollution. CAMx is designed to:

- simulate air quality over many geographic scales;
- treat a wide variety of inert and chemically active pollutants such as O_3; inorganic and organic PM ($PM_{2.5}$/PM_{10}); mercury and other toxic pollutants; and be computationally efficient and easy to use.

CAMx can be used with inputs from any meteorological model and emission inputs from any emissions processor. CTMs can be applied in both forward and backward directions. In case of backward dispersion modelling, the model starts from concentrations at the receptor location and traces back the air parcels that produced these concentrations and the potential sources. This backward approach can be considered as receptor oriented as it does not use pollutant emissions.

The USEPA has called **receptor-oriented approaches** receptor models. They are mathematical or statistical procedures that use and compare the profiles of gases and particles (chemical and physical characteristics) at sources and receptors in a given area to estimate the presence and fraction of source contributions at receptor locations. Unlike CTMs, receptor models do not use pollutant emissions, meteorological data and chemical transformation and deposition mechanisms to estimate the contribution of sources to receptor concentrations (USEPA, 2007). Receptor models cannot identify the contribution of individual sources if several sources of the same type and emission characteristics are located in the area considered.

4.5 Implementation in Sub-Saharan Africa

In order to undertake air quality modelling rapid emission inventories need to be compiled or improved applying for instance the methods discussed in Section 4.3. Emissions inventories provide relatively accurate baseline data on which to provide forecasts of air quality derived from air quality modelling. Many models can be downloaded free of charge from the internet together with users' manuals. SSA countries should take advantage of this. **Dispersion models** are useful in determining the extent and coverage of pollutants from different sources. They can provide estimates of air pollutant concentrations from proposed industrial plants for compounds too expensive or difficult to measure in order to achieve spatial coverage of monitoring estimates. Dispersion models can also be useful for estimating the contribution of transboundary air pollution in a particular country. Thus, the use of dispersion models in AQM is a low cost option *par excellence*. The Gaussian dispersion models and/or Puff models should be used in SSA. Other models require more elaborate data input and experience which may not be available in SSA countries outside South Africa. However, a nationally accredited agency for the validation of models and input data should ensure validated predictions of air pollution concentrations on the basis of models.

Source apportionment techniques can be useful for estimating the contribution that different source types make to ambient pollutant concentrations in cases where emission inventories are absent. Thus they can provide first estimates of the key sources which will be useful in SSA cities. Evaluation methods are, however, already quite sophisticated and request some statistical understanding.

4.6 Summary

Dispersion models can be used to estimate air pollutant and GHG concentrations from stationary and mobile sources, particularly in cases where it is too expensive to monitor or for compounds for which no monitoring methods exist. The costs of estimating air pollutant concentrations using dispersion models are much lower than the cost of monitoring air pollutant concentrations.

Dispersion models need reliable input data, both from emission inventories and meteorological measurements or models. They should be validated by means of monitoring data, if available.

There are several source apportionment approaches which help to determine the contribution of individual source types to air pollution. These approaches do not replace emissions inventories but may be a first step to assess the relevance of different sources of air pollution. Table 4.2 provides a summary of the low cost tools available for monitoring.

Table 4.2: Summary of the low cost tools available for monitoring

Objective	Low Cost Option	Description	Examples
The objective for air quality modelling is to support and strengthen national and local air quality estimates and allow source apportionment and estimations of transboundary pollution. This includes quality assured emission data; regional harmonisation of dispersion models and quality assured topographical and meteorological input data for more advanced models.	Simple Dispersion Models	A dispersion model estimates concentration levels at any point in space and, depending on the availability of meteorological information, for any time. Box models illustrate the simplest kind of material balance. To estimate the concentration in a city, air pollution in a rectangular box is considered under the major simplifying assumptions. A Gaussian dispersion model is normally used for considering a point source such as a factory smoke stack. It attempts to compute the downwind concentration resulting from the point source. An airshed model, rather than tracking the plumes of contaminants from point, line and area sources, divides the whole area into a grid of cells, and models what happens as contaminants are moved by the wind from one cell to the next. Airshed models can also take account of chemical transformations that occur in the atmosphere.	The USEPA´s AERMOD Modelling System uses a Gaussian dispersion model. More advanced dispersion and airshed models require more detailed emission data in order to give a precise and representative estimate for the area under consideration. More advanced models currently available include: The Air Pollution Model (TAPM) CALPUFF (Puff model) Urban Airshed Model variable grid (UAM-V) CALGRID Models III photochemical-aerosol modelling system.

Chapter 5

Monitoring

5.1 Objective

The objective for monitoring air pollutants is to establish and/or strengthen national and local air quality monitoring programmes. These include:

- representative coverage of outdoor air quality monitoring systems;
- periodic review of air quality monitoring issues;
- production of baseline data;
- satisfactory maintenance of monitoring systems and procuring spare parts;
- obtaining data of known quality and their wide dissemination;
- focus on quality control and quality assurance of monitoring programmes;
- close collaboration among different monitoring agencies;
- use of standard operating procedures for monitoring, for data analysis and presentation;
- harmonisation of monitoring networks and devices;
- monitoring of transboundary air pollution;
- monitoring of air quality in urban and peri-urban areas; and
- hotspot monitoring.

Because of limited resources, measures to monitor air quality in SSA should focus on the key pollutants and sources. Air quality monitoring strategies in cities of SSA may thus be quite different from those adopted in developed countries.

5.2 Situation

Routine air quality monitoring is not performed in the majority of SSA countries. Monitoring stations exist in eight SSA countries (Botswana, Ghana, Madagascar, Nigeria, South Africa, Tanzania, Zambia, and Zimbabwe). Monitoring stations are being installed in Senegal (Dakar). In those countries where monitoring stations are operational, these are located in capital cities or in cities with heavy industry (e.g. Botswana (Gaborone, Selebi Phikwe), Ghana (Accra), Madagascar (Antananarivo), Tanzania (Dar es Salaam) and Zimbabwe (Harare)). Nigeria (Lagos) and Zambia (Lusaka) have removed monitoring stations which have not been operational for some years. In Zambia, monitoring is performed by industry; in other SSA countries the Environmental Protection Agency or the Ministry of Environment is responsible for monitoring. Some countries such as Congo-Brazzaville are already planning the implementation of a monitoring network.

Air pollutant concentration monitoring is used to test compliance with air quality standards. Standards have been set or proposed in eight of 27countries (Botswana, Burkina Faso, Ghana, Kenya, Mauritius, Nigeria, Tanzania, Uganda, and Zambia) reviewed by Schwela (2007). In Burkina Faso, Kenya, Mauritius, Nigeria and Uganda enforcement is not possible due to the lack of monitoring data. Countries which are monitoring but have not adopted national air quality standards (e.g. Ethiopia) use USEPA standards or WHO guideline values for compliance testing during monitoring campaigns.

The need for more and improved air quality data in SSA countries to facilitate better AQM is becoming increasingly apparent. In particular, there is a need for improved geographic coverage and consistency of quality, and more data are required for large cities and surrounding areas, which can experience severe episodes of air pollution. However, there can be serious local, technical and other problems in obtaining and ensuring reliable data. These problems include training and service difficulties, climate extremes, power supply variability, and lack of foreign exchange for equipment as well as the lack of consumables and replacement parts for essential equipment.

5.3 Air Quality Monitoring

The first step in designing and implementing any air monitoring system is to define its overall objectives. Each organisation is likely to have its own specific objectives for air quality monitoring.

Typical Air Quality Monitoring Objectives

- Assessment of population/ ecosystem exposure
- Public information
- Providing objective input to planning
- Local or national air quality management
- Identification of pollution sources or risks
- Evaluation of long-term trends
- Establishing a sound scientific basis for policy development
- Determining compliance with air quality standards/targets

The main pollutants of interest in outdoor air in urban environments are CO, O_3, NO_x, SO_2, PM, and lead. Lead is of less concern due to the phase-out of leaded gasoline. In addition, increasing attention is being paid to toxic air pollutants (termed ‘air toxics’ in the US) such as PAHs, acid aerosols and heavy metals such as nickel, cadmium and arsenic. The extent to which different pollutants contribute to air quality problems in any city or country will depend on a wide variety of factors; these include the extent of industrialization, local controls, major types of transportation, and meteorological and topographical characteristics.

In cities, monitoring is usually undertaken at selected sites, rather than at points on a grid. Sites should be representative of specific location types covering, for example, characteristic central urban, industrial, and residential, population-exposure, commercial or kerbside areas. Appropriate site selection will involve consideration of a variety of possible data inputs.

Important Factors in Monitoring Site Selection

Sites will be selected taking into consideration:

- Monitoring objectives
- Sources and emissions in area
- Meteorology and topography
- Existing air quality data
- Model simulations
- Demographic/health/land use data

As well as site conditions, for example:

- Access
- Potential vandalism
- Site sheltering
- Infrastructure (electricity, telephone etc.)

Although specialised instrument servicing skills may be difficult to obtain in SSA, good laboratory skills are often available. In these circumstances, state-of-the-art automatic equipment may not be the best means of obtaining reliable monitoring data, as under some local conditions it may not be possible to meet the demands of these techniques in the long-term.

Data quality objectives will be the key determinant in the selection of monitoring technology. However, practical considerations are also vital. For example, these include local economic constraints, and the availability of skilled labour. There tends to be a clear trade-off between instrument cost, complexity, reliability and performance. Relatively simple and inexpensive methods have been developed as potentially credible alternatives to the more demanding automatic monitoring systems.

Four major air quality monitoring methods exist (see Table 5.1). These are, in increasing order of expense and complexity:

1. *Passive sampling*: a sample exposed during a certain time is collected without the use of power supply.
2. *Active sampling*: a sample exposed during a certain time is collected by pumping the pollutant to the sampler.
3. *Automated monitoring*: the sample is analysed on-line and in real-time.
4. *Remote sensing*: a sample collected along a path between a light source and a detector is analysed in real-time.

Table 5.1: The major Instrumented air monitoring techniques

Method	Advantages	Disadvantages	Capital Cost
Passive Samplers	• Very low cost • Very simple • No dependence on mains electricity • Can be deployed in very large numbers • Useful for screening and mapping	• Unproven for some pollutants • In general, only provide monthly and weekly averages. • Labour-intensive deployment/analysis • Slow data throughput	US $10-50 per sample
Active Samplers	• Low cost • Easy to operate • Reliable operation/ performance • Historical dataset	• Provide daily averages • Labour-intensive sample collection and analysis • Laboratory analysis required	~US $ 2000-20,000 per unit
Automatic Analysers	• Proven • High performance • Hourly data • On-line information	• Complex • Expensive • High skill requirement • High recurrent costs	~ US $ 10000-25,000 per analyser
Remote sensors	• Provide path or range-resolved data • Useful near sources • Multi-component measurements	• Very complex and expensive • Difficult to support, operate, calibrate and validate • Not readily comparable with point data • Atmospheric visibility and interferences	~ US $ 100k - 300k per sensor, or more

The simplest and cheapest-method that meets the specified monitoring objectives should be selected. Inappropriate, complex or failure-prone equipment can severely disrupt overall network performance limiting the usefulness of the data gathered. Automatic analysers will be required if short-term concentration peaks and resulting acute health, amenity or ecosystem effects are to be investigated. However, active or passive samplers will often be adequate if only long-term baseline levels or trends are of importance.

Many baseline monitoring, spatial screening and site selection functions can be sufficiently served by active or passive sampling methods. Automatic analysers have significant cost and operational penalties, and should normally only be considered for long-term measurements (typically 5-10 years) and/or when the data quality objectives require them (e.g. for time-resolved measurements).

Remote sensors can provide integrated multi-component measurements along a specified path, but these devices remain- for the most part- complex and expensive; as such, they will usually only be considered for special applications.

Similarly, biomonitoring techniques can provide a cheap and flexible way of identifying the presence of effective levels of pollution and/or areas. Biomonitors are passive monitors consisting of lichens, grass, mosses and other plants. They are exposed over longer time periods between 14 days to 180-365 days. Effect endpoints include uptake of chemical compounds, growth symptoms and injuries such as chloroses and necroses. Biomonitors can provide detailed measurements and allow the estimation of exposure concentrations once a concentration-response relationship has been assessed. However, they have not been sufficiently developed to be applied in standard monitoring programmes.

5.4 Rapid Monitoring Techniques

Passive samplers involve the collection of air pollutants without the use of pumps. Passive samplers have many advantages but also some disadvantages over other approaches and so should be regarded as complementary to other techniques, such as continuous or semi-continuous fixed instruments, and manual pumped methods. Because they are generally unobtrusive and require minimal operator involvement, passive samplers are usually the most cost-effective solution to a measurement problem. Since all analysis can be performed centrally, highly skilled personnel are not required on-site. The advantages of low cost and simplicity facilitate the deployment of passive samplers in large-scale networks. They can also have advantages in uniformity, quality assurance and quality control. Whereas active samplers have problems with noisy pumps, passive samplers are silent and small and therefore easy to site.

Passive samplers do not have to be calibrated in the field, which is also the case for active samplers but not for automatic analysers. There are many types of passive samplers such as bulk collectors, surrogate surfaces, flux samplers and diffusive samplers. Their main disadvantage, compared to methods where the sampling rate can be controlled directly by means of a sampling pump, is that they are only useful for relatively long exposure times, usually at least one day, resulting in time-weighted average concentration measurements. The most advanced passive samplers are diffusive samplers. Diffusive samplers are special passive samplers, which collect air pollutants using absorbent material.

Diffusive samplers are devices capable of taking samples of gas or vapour pollutants from the atmosphere, at a rate controlled by a physical process such as diffusion through a static air layer, or penetration through a membrane, but which does not involve the active movement of air through the sampler (Berlin et al. 1987). This definition implies that, in general, diffusive sampling is not practicable for dust or suspended particulate matter.

The uptake rate of the gas should be exclusively controlled by molecular diffusion and should not involve active movement of air. As a consequence, the physical dimensions of the sampling device are the main factor governing the diffusive sampling rate. Diffusive samplers can be divided into the following types: tube, badge and radial (see Table 5.2). Different samplers are appropriate for different gaseous species.

Table 5.2: Different types of diffusive samplers

Diffusive samplers are generally designed either in a tube-type configuration with one end open (so-called "Palmes tubes"), used with or without a membrane at the open end or a windshield, or in a shorter badge-type configuration, where the open end is protected by a membrane filter or other wind screen. In either case, the closed end contains an absorber for the gaseous species to be monitored.

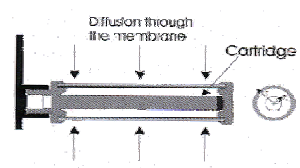
Tube and badge type samplers are mainly used for the detection of SO_2, NO_2, O_3 and CO. The low uptakes of tube type and badge type samplers - and hence the longer exposure period required - prohibits the monitoring of short-term concentrations.

A radial diffusive sampler for ozone and other compounds, called Radiello has a higher sampling rate and a lower detection limit (FSM, 2000; Buck, 2008). The diffusive surface is cylindrical instead of plain and the adsorbing substrate is contained in a coaxial cylindrical cartridge. The diffusive path is therefore parallel to the radius and not to the axis.

The Radiello Diffusive Sampling System provides the ability to conduct high-resolution concentration measurements of O_3, NO_2, SO_2, VOCs, hydrogen fluoride (HF), hydrogen chloride (HCl), benzene-toluene-xylenes (BTX), and aldehydes.

Tube sampler

Badge sampler



Radial diffusive sampler

Active samplers use electrical power to draw air though a chemical or physical collection medium. Collection can be made via absorption, adsorption, impaction, filtration, diffusion, reaction or combination of these processes. The samples collected are subsequently analysed to determine the concentration of the pollutant(s) of interest. The volume of sampled air can be varied and sufficient volumes of air are sampled to allow daily or hourly average concentrations to be measured.

Active samplers are relatively simple, inexpensive, manual methods, which have been widely used for determining SO_2, NO_x and O_3. These methods involve either absorption or chemical reaction in an absorbing solution, or collection on chemically impregnated filters (see Figure 5.1). Other active sampler methods are either much more expensive or more technically demanding and hence not widely used for routine monitoring.

For active systems, sampling equipment costs are of the order of US$ 1,000 per unit whilst an analytical spectrometer, if required, costs in the order of US$ 10,000. In addition, a reasonably stocked analytical laboratory and trained, experienced technicians are required.

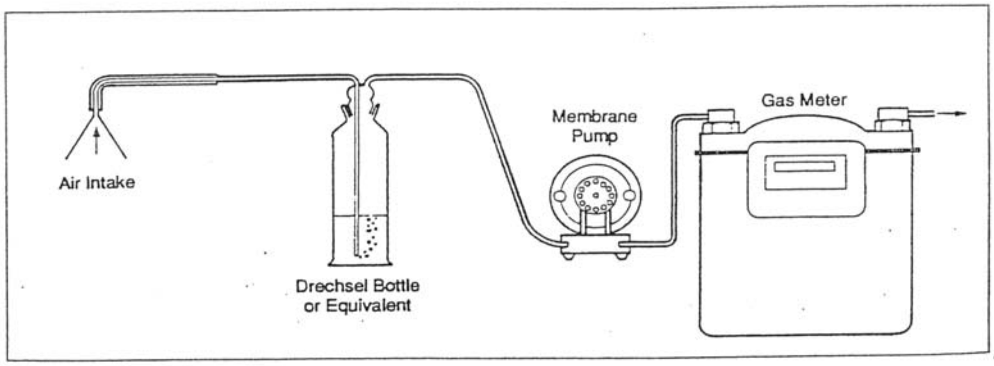


Figure 5.1: Active sampler for sulphur dioxide

Source: UNEP/WHO (1994)

For PM the most accurate way to determine aerosol mass concentration is to pass a known volume of air through a filter and then to determine the increase in mass of the filter due to the aerosol particles collected. For traceable and robust measurements, samplers must be fitted with a tested PM_{10} or $PM_{2.5}$ inlet head and an accurate flow control system. Figure 5.2 shows a high volume sampler for TSP and PM_{10} (LSA, 2007).

The MiniVol Portable Air Sampler (see Figure 5.3) samples ambient air at 5 litres/minute for PM (TSP, PM_{10}, $PM_{2.5}$) and/or non-reactive gases (CO, NO_x) simultaneously. The MiniVol provides results that approximate reference method data. Particle size separation is achieved through impaction. The PM is collected on 47 mm filters, which must be weighed pre- and post-exposure to determine particle concentrations (PO 1996-2007). The cost of a PM_{10} MiniVol sampler is approximately US$ 4,000.

Figure 5.2: High volume sampler for TSP

Source: LSA (2007)

Figure 5.3: The Minivol sampler for PM_{10}

Source: USEPA (2006)

Automatic analysers can provide high-resolution measurements (typically hourly averages or better) at a single point for most of the criteria pollutants (SO_2, NO_2, CO and PM), as well as for other important species such as VOCs. The sample is analysed on-line and in real-time, usually by electro-optic methods: ultraviolet or infrared absorption, fluorescence or chemiluminescence are common detection principles. To ensure the data from automatic analysers are accurate and reliable, a high standard of calibration, maintenance, operational and quality assurance/control procedures is invariably required.

Prospective users of automatic analysers need to be aware of the requirements for associated infrastructure, such as suitable site housing (usually with air conditioning), instrument service/repair and calibration requirements and, data handling and checking requirements. These types of analyser are often incorporated into monitoring sites together with the automatic gas analysers. In addition, meteorological parameters (especially wind speed and wind direction) are sometimes monitored at the same location.

An important requirement for the operation of automatic air pollution analysers is the provision of sufficient manpower and fiscal resources for on-going support of the analysers after purchase. Annual service and repair costs are typically approximately 10 per cent of the purchase price and, as a rough guide; an additional 10 per cent will be required for the provision of calibration and data handling requirements. Suitably skilled and trained staff must also be available for these tasks. In addition, operation of automatic analysers will be very difficult in areas where the electricity supply is of poor quality or unreliable.

Automatic analysers for PM include light scattering instruments. Light scattering by small particles suspended in gases is widely applied to obtain information about the concentration of airborne particles. Instruments based on this principle combine *in situ*, real-time, measurements of air sampled directly by the instrument, with a high degree of automatisation. These instruments can be broadly divided into two categories: nephelometers and photometers. The **nephelometer** is used for outdoor measurements of suspended PM by detecting the light of a light beam reflected from the particles (QEPA, 2007).

Photometers are perhaps the most commonly used direct-reading aerosol instruments and have been commercially available for over 25 years in a variety of configurations. Photometers have many advantages over the traditional gravimetric sampler: they provide real-time data; they are simpler to use and in the long-term they are less expensive to operate. They can be used to identify immediate hazards, to screen for prioritisation of further air sampling, and to enable measurements of spatial and temporal variation in particle concentrations in the environment under investigation. However, their major disadvantage is that they do not directly measure gravimetric mass. Since air quality standards for PM are usually based on utilization of gravimetric methods of sampling, it is therefore necessary to correlate photometer signals with the gravimetric mass concentration of aerosol.

Most photometers are factory calibrated against a gravimetric reference using the respirable fraction of standard Arizona Test Dust (ATD) according to ISO12103-1:1997. However, the factory calibration could depart quite significantly from the gravimetric measurements in environments with high concentrations of combustion sub-micrometre particles or other aerosols that differ significantly from ATD.

The **DustTRAK™** Aerosol Monitor (see Figure 5.4) is a portable, battery-operated laser photometer with real-time mass concentration readout and data logging capability. The monitor provides reliable exposure assessment by measuring particle concentrations corresponding to respirable size ($PM_{4.0}$), PM_{10}, $PM_{2.5}$ or $PM_{1.0}$ size fractions (TSI, 2007). The cost of a DustTrak is approximately US$ 6,000.

Figure 5.4: the DustTrak Aerosol monitor

Source: TSI (2007)

Table 5.2 presents more sophisticated and expensive automatic analysers which are currently available.

Table 5.2: Examples of automatic analysers for particulate matter sampling

Sampler	Description
Beta-ray absorption analyser	o Beta radiation passing through the collected sample is attenuated, and the mass collected is proportional to the degree of the attenuation. o Advantage: it does not require further laboratory analyses for mass determination. o Disadvantages: • use of the radioactive source • the long response time • inherent inaccuracy arising from the fact that the sensitivity is somewhat dependent on the material sampled • High costs.
Tapered Element Oscillating Microbalance (TEOM)	o The particle sample is collected on a filter mounted on the thin end of a tapered oscillating hollow element, which is fixed at its thick end. The resonant frequency decreases with the mass loading of the filter. This change in resonant frequency is converted to a mass measurement. o Advantages: • fast response time • near real time results. o Disadvantage: High costs.
Nephelometer	o Operates on the principle of the scattering of light by particles. Light reflected by particles in the sampling chamber is detected, amplified and displayed o Advantages: • Can be used to estimate visual range • Particularly sensitive to ultrafine particles o Disadvantages: Does not directly measure gravimetric mass • Calibrated with Arizona dust • High costs.

5.5 Quality Assurance and Quality Control

Whatever the objectives of air quality monitoring (e.g. health impact assessment, assessing traffic or industrial impacts, planning, policy development or providing public information) measurements will need to be accurate and reliable if they are to prove useful. This is why QA/QC is a key component of any monitoring programme. QA/QC is defined as a system of activities that assures that measurements meet defined standards of quality with a stated level of confidence. QA relates to the measurement process, whilst QC is concerned primarily with outputs. Proper QA/QC is also essential in ensuring the comparability of measurements made between networks and monitoring programmes in different parts of SSA. QA/QC is therefore a basic tool in ensuring that data within and among different networks are harmonised.

Without QA/QC, measured data will not provide a sound basis for assessment of population health effects of air pollution or for effective AQM; as a result, any investment of money, time and effort made in monitoring will have been wasted.

Before embarking on a measurement programme, it is necessary to draw up a detailed QA plan covering all aspects of quality assurance and control. The QA programme will cover all the important pre-measurement phases of monitoring, ranging from definition of data quality objectives, and system design and site selection through to equipment evaluation, selection and deployment, and operator training. QC functions will cover directly measurement-related activities including network operation, calibration, data handling, review and training.

The main activities involved in QA/QC systems for air monitoring include:

- Definition of overall monitoring objectives;
- Using these to determine data quality objectives (DQOs);
- Network design and management structures;
- Selection of representative monitoring points;
- Adoption of cost effective instrumentation;
- Operation and maintenance of systems;
- Establishment of calibration/traceability chain; and
- Data review, validation and usage.

Data QA/QC issues are best addressed at the earliest possible stage in any monitoring study. The scope and complexity of the QA/QC programme will be influenced by the monitoring objectives as well as by economic constraints and the availability of skilled manpower. The broad principles of QA/QC practice will apply for any type of monitoring methodology.

However, the programme details and human resources required will depend strongly on the type of instruments used. With samplers, more emphasis will need to be placed on the quality assurance of laboratory-based activities involving the analysis of collected samples; for automatic analysers more effort will be required at the point of measurement. In general, the workload involved in data-related quality control activities will increase with the quantity of data throughput and the rigour of the DQOs. Under any circumstances, it is most important that all staff should be trained to regard quality assurance and control as an integral and vital component of any air quality monitoring programme.

Quality assurance and control must be regarded as an on-going process, in which revised or more sophisticated procedures may be undertaken as circumstances change, a new need arises, or additional resources become available.

As a minimum requirement for QA/QC programmes, it is recommended that the operational practice for existing networks should be formalised and documented. Full quality assurance/control programmes as used, for example, in national networks may not always be applicable to local surveys. Nevertheless, smaller organisations unable to develop QA/QC programmes in-house should use proven methodologies wherever possible, and seek advice from recognised laboratories with appropriate QA/QC experience. The development and implementation of QA/QC-Systems can have important resource implications in terms of expenditure, skilled manpower and time. These should be recognised early in the process of network planning and development, so that appropriate financial provision, both up-front and ongoing, can be made.

Many publications on QA/QC (e.g. UNEP/WHO, 1994) in air pollution exist which could be used to set up QA/QC plans and obtain data of known quality.

Wide dissemination of information gained from air quality data is an important means to inform all stakeholders and the public. The use of an air quality index (AQI) can inform the general public. In order to avoid creating fears in the population by communicating risks from air pollutants, public risk perception should be understood.

5.6 Implementation in Sub-Saharan Africa

Regarding the compounds to be monitored, PM is of particular concern in SSA countries with respects to health impacts. SSA Countries which do not yet monitor should undertake pilot projects to start monitoring campaigns with a combination of simple monitoring devices such as diffusive monitors and simple devices for PM monitoring (e.g. MiniVols and DustTraks). These monitors are useful in order to determine if there are problems with gaseous and particulate air pollution. The use of automatic analysers should only be initiated if passive samplers and low cost particle monitors have indicated that there are problems. It is not cost-effective to employ automatic analysers at the very beginning of air pollution monitoring and find out that there is no problem.

If a network of monitors has been proven necessary from the pilot phase a combination of a few automatic samplers and a multitude of diffusive samplers which are sited to monitor air pollution in a spatially and time representative way are the most cost-effective monitoring methods. Thus, a small hybrid network of monitoring stations with a station of automatic samplers, some DustTraks and/or MiniVol samplers for particles and diffusive samplers for the gaseous compounds can constitute a sufficient and cost-effective hybrid network for air quality monitoring in SSA countries. While automatic samplers provide time series of monitoring data, diffusive samplers are very useful for providing spatially representative data at a lower time resolution. Such a hybrid network could deliver information of known quality on the air quality situation in SSA countries. An important part of the network would be a QA/QC plan which ensures that data are of known quality. Installation of a monitoring network involves the consideration of the supply of spare parts in order to make the network sustainable. The situation experienced in Nigeria and Zambia, where an air quality monitoring network was not sustainable, should be avoided.

Reviewing the objectives and procedures of air quality monitoring is useful in view of the permanently changing urban situation since pollutants important in the past may not necessarily continue to be so important in the future.

Monitoring is usually performed in residential areas. Hotspot monitoring may be useful for assessing exposure at highly polluted locations in close proximity to sources (e.g. near industrial sites). Kerbside monitoring may also be needed to especially assess exposure to pollutants emitted by vehicles.

For epidemiological studies, it is useful to have urban and peri-urban monitoring if the exposed population lives in the urban area and the control population in the peri-urban area. In the absence of sources in the peri-urban area and with certain prevailing winds and local conditions, the pollution in the peri-urban area may be representative of transboundary air pollution.

Monitoring of transboundary pollution in SSA for compounds such as PM_{10}, $PM_{2.5}$ and O_3 needs a careful selection of sites in order to be able to separate the transboundary contribution from that of urban areas. The monitoring of transboundary pollution is particularly important if it is of the magnitude of local urban pollution.

Different monitoring and funding agencies working in the same urban area can profit from collaboration by combining their forces and minimising total costs.

5.7 Summary

Monitoring objectives and data quality objectives should be clearly formulated in any air quality monitoring programme.

Air pollutant concentration monitoring is often used to test compliance with air quality standards. The results of monitoring can provide feedback for the continuous process of improving air quality by lowering the standard values. Monitoring can also serve to establish associations between air quality and health and environmental impacts. The compounds to be monitored depend on the local situation with PM, CO and O_3 being the most important outdoor pollutants, and PM and VOCs being the most important indoor pollutants.

QA/QC is the backbone of any air quality monitoring programme. The establishment and implementation of QA/QC programmes and adoption of QA/QC plans ensure that air quality monitoring data (and emissions data and health and environmental monitoring data) are reliable and provide a sound basis for policy making. Table 5.3 provides a summary of the low cost tools available for monitoring.

Table 5.3: Summary of the low cost tools for monitoring

Objective	Low Cost Option	Description	Examples
The objective for monitoring air pollutants is to establish and/or strengthen national and local air quality monitoring programmes. These include: Representative coverage of outdoor air quality monitoring systems; Periodic review of air quality monitoring issues; Production of baseline data; Satisfactory maintenance of monitoring systems and procuring spare parts; Obtaining data of known quality and their wide dissemination; Focus on quality control and quality assurance of monitoring programmes; Close collaboration among different monitoring agencies; Use of standard operating procedures for monitoring, for data analysis and presentation.	Rapid Air Quality Monitoring Techniques	Major air quality monitoring methods include: Passive/diffusive sampling: a sample is collected over a certain exposure time without the use of power supply. Active sampling: a sample integrated over exposure time is collected by pumping the pollutant to the sampler. Automated monitoring: the sample is analysed on-line and in real-time.	Passive/diffuse samplers include the tube and badge type samplers mainly used for the detection of SO_2, NO_2, O_3 and CO. The Radiello Diffusive Sampling System used to measure O_3, NO_2, SO_2, volatile organic compounds (VOC's), hydrogen fluoride (HF), hydrogen chloride (HCl), benzene-toluene-xylenes (BTX), and aldehydes. The High Volume Sampler is an active sampling device for TSP and PM_{10}. The MiniVol Portable Air Sampler is an automated monitoring device that samples ambient air for PM (TSP, PM_{10}, $PM_{2.5}$) and/or non-reactive gases (CO, NO_x) simultaneously. The DustTRAK™ Aerosol Monitor is a portable, automotated (i.e. battery-operated) laser photometer with real-time mass concentration readout and data logging capability. The monitor provides reliable exposure assessment by measuring particle concentrations corresponding to respirable size ($PM_{4.0}$), PM_{10}, $PM_{2.5}$ or $PM_{1.0}$ size fractions.

Chapter 6

Health and Environmental Assessment

6.1 Objective

To establish and/or strengthen national and local programmes which monitor the health and environmental impact of air pollution in a harmonised way. This includes:

- undertaking long-term studies of health and environmental impacts due to air pollution;
- strengthening institutional capability;
- assessing of health, environmental and economic impacts of air quality;
- augmenting and disseminating information on health and environmental impacts;
- ensuring spatial and time representativity of monitoring sites for actual exposure of humans and the environment.

6.2 Situation

The impacts of urban air pollution on human health and the environment are rarely assessed in SSA countries. Some studies have been undertaken in Benin, Botswana, Ghana, and Nigeria. The most comprehensive studies are of blood lead levels in Ghana before and after the phase-out of lead, and a study on the link between air pollution and health impacts. Nigeria has conducted a human health impact survey; other studies addressed acid precipitation, solar irradiance, greenhouse gas effects, pollutant levels in biological species, and urban climate. In Botswana small scale studies undertaken by the city of Selebi Phikwe investigated impacts of SO_2 on the population and the environment. Zimbabwe has compiled some anecdotal evidence on health effects. In Burkina Faso and Senegal estimates of the cost of air pollution in terms of percentage reduction of the gross domestic product have been undertaken. On the basis of qualitative and anecdotal observations, Guinea, Mali, Uganda and Zambia suggest that respiratory symptoms and other public health impacts may be due to air pollution. In addition, Mali reports an increase in accidents due to reduced visibility caused in part by PM pollution. The POLAIR project of Gabon (see Schwela, 2007) plans epidemiological studies to estimate human health impacts caused by air pollution.

There is a lack of short- and long-term studies of health and environmental impacts due to air pollution in practically all SSA countries. Table 6.1 presents the results of recent investigations on the impact of air pollution on vegetation in South Africa (van Tienhoven and Scholes, 2003). The absence of air quality monitoring capability in most SSA countries, insufficient institutional capability and the lack of a national health information system may be the reasons for this scarcity in health and environmental studies.

Table 6.1: Observed and estimated impacts on vegetation in South Africa

Plant species	Location	Observed impact	Possible compounds	Likelihood of causal association	Reference
Field research					
Vegehtation composition	Highveld	Composition degradation	SO_2	Low	van Rendsburg (1993)
Freesia variety	Southwestern Cape	F content; visible injury	F	High	Botha et al. (1990)
Commercial forests	Mpumalanga; KwaZulu-Natal	Foliar symptoms (Chlorosis)	SO_2, NO_x, PM	High	Olbrich (1990; 1992; 1993)
Experimental research					
Beans	Cape Town area	Decrease in dry mass and leaf surface	SO_2	Medium	Botha et al. (1990)
Tobacco Bel-W3	Mpumalanga; KwaZulu-Natal	Leaf injury	O_3	High	Blair (1998)
Simulation					
African Maize	Southern Africa	Ozone burden	O_3	Possible	van Tienhoven et al. (2006)

6.3 Determining the Health Hazards due to Air Pollution

To understand the impact of air pollution on human health it is necessary to understand the health hazard resulting from air pollution. A health hazard is a source of danger or an agent that can harm human health (qualitative notion). The health risk is the probability that health impact will occur (quantitative notion). In order to assess health risks presented by hazards it is necessary to gain information on how hazards occur in a particular environment; the population groups which are exposed; the level to which they are exposed; the duration of exposure; and health impacts that these hazards could cause or have caused (i.e. dose-(exposure-) response relationships). In the assessment of risks due to air pollution is will be necessary to consider home, workplace, community and larger-scale environment. The most common air pollutants in daily life are PM, SO_2, NO_x, CO, CO_2 and O_3.

Epidemiology is the study of the distribution and determinants of health-related states or events in specified populations. Environmental epidemiology is the branch of epidemiology that specifically deals with environmental exposure as determinants of health. Findings from epidemiological studies are based on observations of human subjects only and therefore are more directly representative and applicable to actual situations in daily life. Table 6.2 outlines the different types of epidemiological studies available.

Data from epidemiological studies or human volunteer studies or are normally used *a priori* for establishing environmental health criteria/standards wherever possible. For most environmental chemicals, epidemiological studies or human control studies are generally not available. For key air pollutants, such as PM, recent epidemiological and time-series studies have shown statistically significant associations between PM exposure and mortality and morbidity. More evidence is needed to establish a causal relationship and to further explore the underlying mechanisms that result in health impacts.

Animal data can contribute to establishing the causal relationship and to further exploring the underlying mechanism for the development of diseases due to exposure to a toxic chemical. The findings of animal toxicological studies have the advantage of being able to identify the adverse health effects specifically and to pin-pointing the dose/effect relationship more precisely. It is both unfeasible and unethical to try to test the result on humans. However, animal studies have a number of limitations. Firstly, exposure levels in animal studies are usually much higher than those encountered in the real environment; the exposure route may not be relevant with respect to human exposure; the exposure period may not be sufficiently long for the study purpose. Secondly, genetic disposition, metabolic processes, sensitivity, disposition towards diseases and other properties may differ between humans and animals.

The assessment of human exposure to air pollutants is a part of total risk assessment, and a necessary part of AQM where it contributes to information on prioritising abatement measures. Exposure assessment examines outdoor air conditions in ambient air where people move and indoor air conditions (e.g. in homes and offices). A number of different approaches to exposure assessment have typically been used these include the following in increasing order of sophistication:

- classification of individual exposure (high versus low);
- measured or modelled outdoor concentrations;
- measurement of indoor and outdoor concentrations;
- estimation of personal exposure using indoor, outdoor and other micro-environmental concentrations along with time activity diaries;
- direct measurement of personal exposure; and
- measurement of biomarkers of exposure such as blood levels of heavy metals, carboxy-haemoglobin or endocrine disruptors.

Clearly, the least sophisticated approach in classifying exposure groups using a categorical variable (such as homes with gas versus electric cooking stoves for NO_2 impact assessment) could lead to significant exposure misclassification bias. However, many existing environmental health studies are based on ambient or community surveillance monitoring data. Humans are exposed to many types of pollutants involving different pollutant sources and locations other than outdoor pollutants and monitored ambient environments (e.g. PM, NO_2, VOCs). For reactive pollutants, such as O_3, indoor pollution levels are significantly lower than the outdoor concentrations. Since people spend more time indoors, personal O_3 exposure is more closely related to indoor than outdoor O_3 concentrations. In general, therefore, exposure models based on ambient data only are less accurate than the micro-environmental models that combine indoor and outdoor concentration measurements (or predictions) with time-activity patterns.

Table 6.2: Different types of epidemiological studies

Cross-sectional studies	Cross-sectional studies examine the association between an environmental exposure and prevalence of a certain disease (the proportion of the population affected) at a particular point in time or during a short period of time. Estimates of exposure and measurement of personal disease characteristics are made at the same time. If a specific cause-effect relationship is suspected to exist, an analytical study can then be conducted to evaluate the quantitative relationship between exposure and health effect by following a population over a period of time. If the study design incorporates all the information contained in the person-time experience of the study population, it is called a cohort study.
Cohort studies	Cohort studies are used to assess long-term health effects of acute exposures to environmental hazards chronic effects of long-term exposure to environmental toxic chemicals. If the study design attempts to obtain the same findings by comparing cases of the disease with people without the disease (selected as a sample of the person-time experience of the source population that generated the cases), it is called a case-control study.
Case-control studies	Case-control studies are efficient for studying rare disease cases, especially those with a long induction period. Studies are termed "prospective" if the population is observed over time as events occur. Studies are termed "retrospective" or "historical" if existing records are used and exposure and health outcome are ascertained after they have occurred (Beaglehole et al., 1993). In time-series studies repeated observations of exposure and health endpoints are made over time within the same study population. The analysis centres on comparing variations in exposure status over time with changes in health outcome status over time.
Time-series studies	A time-series studies are based on aggregate data is essentially a temporal comparison study that examines an association between a variable exposure and a concomitant variable health outcome. This method has been used extensively in recent decades in the study of atmospheric air pollution and its impact on health. Since observations are made within the same population, the influence of many confounding factors can thus be avoided.
Descriptive studies	Descriptive studies are based on existing acute and chronic mortality (Rabl, 1998; 2006) or morbidity data (acute and chronic bronchitis, acute respiratory infections, respiratory and cardiovascular hospital admissions, outpatient visits for internal medicine and paediatrics, emergency-room visits and asthma attacks) and patterns of health outcome are examined for specific geographical areas or specified time periods. Birth outcomes and lung function parameters are also often used health endpoints. The main disadvantage of using existing records is that the information they provide may not be fully appropriate for the particular study objective and may not have the required precision for the study purpose.

Table 6.2: Different types of epidemiological studies

Meta-analyses	A meta-analysis is a quantitative analysis of the combined results of several individual studies. This involves locating all relevant studies pertaining to the specific research topic, resolving issues of study quality and conflicting results, calculating summary weights and finally reaching a summary effect or summary risk estimate. Though a meta-analysis method has its limitations, it is a useful technique for summarising environmental epidemiological studies, and for helping people to reach a consensus when the results of several studies conflict with one another.

Air quality standards and guidelines have been established based upon the air pollution impact on human health. The best available background material for the evaluation of health impacts is the USEPA criteria documents (e.g. USEPA, 2006) and the Guidelines for Air Quality (WHO, 2000b; 2005). WHO's guideline values for air quality are set to ensure that the population exposed to concentrations lower than the guideline values should be subject to negligible or - in the case of PM_{10} and $PM_{2.5}$ - relatively small risks of adverse effects. In cases where the guideline value for a pollutant is exceeded, the probability of harmful effects will increase.

Health impacts of air pollution have been described in a number of publications (WHO 2000; 2005; Schwela, 2000). Most studies have been performed in developed countries. Studies in SSA are scarce.

6.4 Health Impacts of Air Pollution

Particulate Matter

Airborne PM is a complex mixture of particles with components having diverse chemical and physical characteristics. Particles are generally classified by their aerodynamic diameter since size is a critical determinant of the site of deposition within the respiratory tract. PM_{10} are particles less than 10 microns in aerodynamic diameter. They can further be divided into coarse particles (from 2.5 to 10 μm), fine particles ($PM_{2.5}$, less than 2.5 μm) and ultrafine (UF) particles (particles of diameter less than 0.1 μm). PM_{10} includes inhalable particles which can penetrate to the thoracic region. $PM_{2.5}$ has high probability of deposition in the airways and alveoli. Particles with different aerodynamic diameters differ in their overall contribution to airborne particle mass and in their origin, physical characteristics, chemical composition, and health effects.

In the past **total suspended particulate matter** (TSP) and **black smoke** (BS) were used as indicators of airborne particles in many countries outside Africa. TSP is still used as an indicator of PM in some countries. Coarse particles contain earth crustal materials, dust from roads, industries and construction activities, and biological material, such as pollen grains and bacterial fragments. $PM_{2.5}$ contains combustion particles, the secondarily formed aerosols (gas to particle conversion), and recondensed organic and metal vapours. Diesel trucks emit particles primarily in the range of 0.1-0.2 μm, i.e. UF particles. The composition of particles varies substantially across cities around the world depending upon local geographical, meteorological conditions and specific sources.

There has long been evidence showing that high levels of PM and other pollutants affect human health. PM_{10} is used as an indicator for airborne PM as there are extensive measurement data of PM_{10} throughout the world. Substantial evidence shows that PM exposure is linked to a variety of adverse effects on mortality (non-accidental all-cause mortality, cardiovascular and respiratory mortality) and morbidity (hospital admissions, out-patient and emergency visits, asthma attacks and acute respiratory infections). The association between PM and adverse health effects is consistent in various cities, both in developed and developing countries.

The risk for adverse health outcomes has been shown to increase with exposure and there is no evidence to suggest a threshold below which no adverse health effects would be anticipated. Several meta-analyses have been conducted to examine the relative risk of short-term mortality associated with a 10 $\mu g/m^3$ increase of PM_{10}. Meta-analyses of European, US and Asian studies show that for each increase of 10 $\mu g/m^3$ of PM_{10} the estimates for short-term all-cause mortality were 0.62, 0.46 and 0.5 per cent, respectively (HEI, 2004) .

Evidence also showed chronic adverse health effects associated with long-term exposure to air pollution. Two long-term exposure studies (i.e. the US American Cancer Society (ACS) study and Harvard Six-Cities cohort study) reported associations between long-term exposure to $PM_{2.5}$ and mortality. A 10 $\mu g/m^3$ increase of $PM_{2.5}$ was associated with approximately a 4, 6 and 8 per cent increase risk of all-cause, cardiopulmonary, and lung cancer mortality, respectively.

The coarse particle fraction ($PM_{10-2.5}$) and TSP were not consistently associated with mortality. Thresholds were not apparent in these studies. However, $PM_{2.5}$ annual mean level of 10 $\mu g/m^3$ is found to be the lowest level at which all-cause, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95 per cent confidence in response to $PM_{2.5}$. Although adverse health effects cannot be entirely ruled out even at such low level, these levels are expected to effectively reduce health risks (Dockery et al., 1993; Pope III et al., 2002).

A wide range of morbidity indicators has been investigated in epidemiological studies. These include hospital admissions, emergency room or clinic visits, symptoms in persons with underlying chronic heart or lung diseases, pulmonary function, and various biomarkers. The risk for acute events, including myocardial infarction (heart attack) and stroke, has also been assessed. In addition to PM_{10} and $PM_{2.5}$, there is considerable toxicological evidence of potential adverse effects of UF particles on human health, but the available epidemiological evidence is insufficient to derive an exposure-response relationship to UF particles.

Gaseous compounds

Gaseous compounds also have an impact on human health. Table 6.3 summarises the health impacts of selected gaseous compounds.

6.5 Environmental Burden of Disease and Air Pollution

When setting priority and intervention targets on air pollution from a public health perspective, it is important for decision makers to know what the total impact of air pollution related disease is and to compare the impacts of different risk factors contributing to such diseases. The **Environmental Burden of Disease** (EBD) approach of WHO provides policy makers with a comprehensive picture of the world's current and future health needs and a method to assess the situation in individual countries and cities (WHO, 2002; 2007). This method quantifies not only the number of deaths but also disability in a population, and combines these into a single unit of measurement of the overall "burden of disease" on the population. The EBD also presents a first estimate of the proportion of mortality and disability that can be attributed to certain risk factors for the disease, in this case air pollution. This approach can be modified to reach a “country” or “city” burden of disease, if needed (WHO, 2006).

To reflect various disease burdens it is critical to provide a single measure of disease burden to capture the impact of both premature death and disability. **The Disability-Adjusted Life Year** (DALY) is adopted as a common measuring index in this context. DALY is the sum of years of life lost to premature death (YLL) and years lived with a disability of specified severity and duration (YLD). Thus, one DALY is equal to the loss of one healthy life year, that is, time lived with a disability and time lost through premature death, i.e.:

$$\mathbf{DALY = YLL + YLD}$$

A “premature” death is defined as one that occurs before the age to which the dying person could have expected to survive. In contrast, disability is difficult to define and quantify. All non-fatal health outcomes of disease are different from each other in their causes, nature, and especially severity. In order to calculate the YLD for different category of disability, it is crucial to set weights for each category of disability based on their nature and severity.

Combined evidence shows that almost all diseases are caused by the interaction of genetic and environmental factors. The amount of disease, disability and death in the world today can be attributed to a selected number of the most important risks to human health. This burden could be lowered if the attributable risk factors are reduced. Risk is defined as the probability of an adverse outcome. Estimating the contributions of selected major risk factors to global, regional or country specific burden of disease in a unified manner can help set priorities for research and policy action in respective areas.

WHO estimated global numbers of premature deaths and DALYs attributable to various environmental risks: unsafe water, sanitation and hygiene may contribute to 1.7 million deaths and 54.2 million DALYs; urban air pollution may attribute to 0.8 million deaths and 7.9 million DALYs; lead may attribute to 234,000 deaths and 12.9 million DALYs. Indoor air pollution was estimated to be 1.6 million excess deaths annually. Taking necessary actions to control and prevent environmental risks could lead to up to 10 years more of life expectancy globally (WHO, 2002). Table 6.4 specifies annual premature mortality due to outdoor and indoor air pollution in 48 SSA countries. Figure 6.1 illustrates the premature deaths per year due to outdoor and indoor air pollution for regions in SSA. Figure 6.2 shows the corresponding DALYs. Figure 6.3 shows that with increasing Grand National Income (GNI) per capita the DALYs per 1000 capita decrease.

Table 6.3: Health impact of selected gaseous air pollutants

Air Pollutant	Health Impacts
SO_2	• After inhalation, SO_2 is absorbed in the mucous membranes of the nose and upper respiratory tract. During exercise, SO_2 tends to reach the lower airways because increased flow rates and mouth breathing reduce the percentage of inspired SO_2 absorbed in the nose and upper airways. • In controlled chamber studies, short-term exposure to high level SO_2 has been found to rapidly induce reversible adverse reduced lung function and increased respiratory symptoms on both healthy and asthmatic volunteers. • Asthmatics are particularly sensitive to SO_2. • Associations between SO_2 exposure and daily mortality (including all-cause, cardiovascular and pulmonary mortalities) were found in most of time-series studies exploring the association between PM and daily mortality and morbidity, but the consistency of SO_2's association with daily mortality appeared to be less than that for PM (ACS study). • An intervention study in Hong Kong suggested a causal relationship between SO_2 exposure and adverse health outcomes (Hedley et al., 2002). • Significant associations between emergency hospital admissions for asthma and SO_2, for chronic obstructive pulmonary disease (COPD) and SO_2 have been reported in some studies, but not in others. • Association between SO_2 and cardiac disease hospital admissions was found both in London and Hong Kong despite their differences in climate and ethnicity. • It cannot be concluded whether SO_2 *per se* is positively correlated with hospital admissions or acts as a surrogate for a mixture of urban air pollutants.
NO_2	• Controlled human studies show that enhanced NO_2 can induce toxic respiratory effects, including reduced host defence against infectious pulmonary disease and enhanced airway responsiveness in exercising healthy subjects to bronchoconstrictive agents, and in asthmatics to allergens and irritant stimuli. • It is very difficult to discriminate the effects of NO_2 from those of other pollutants in epidemiological studies. Many epidemiological studies used NO_2 as a marker or a surrogate for air pollutant mixture from fuel combustion. • Respiratory symptoms in children and bronchial symptoms in asthmatic children have been found to increase with outdoor annual NO_2 concentrations. Reduced lung function growth in children has also been reported linked to increased NO_2 concentrations. • NO_2 daily concentrations are found to be significantly associated with increased all-cause, cardiovascular and respiratory mortality in time-series studies. A meta-analysis on daily mortality and 24-hour NO_2 levels indicated that the overall effect estimate from the multi-pollutant model for all-cause mortality was 0.9 per cent per 45 $\mu g/m^3$ NO_2 (Stieb et al., 2002).

	• The European APHEA-1 study found a 1.3 per cent increase in daily deaths per 50 µg/m^3 NO_2 (1-hour maximum) (Touloumi et al., 1997). The APHEA-2 study (Katsouyanni et al., 2001) found that PM effects on daily mortality were stronger in areas with high NO_2. • The US National Morbidity and Mortality Air Pollution Study (NMMAPS) showed that daily mortality increased from 0.3 to about 0.4 per cent per 18.8 µg/m^3 increase of NO_2. • The results of most of the time series studies on NO_2 and hospital admissions/emergency room visits for respiratory and cardiovascular diseases, as well as doctor visits for asthma in children show an independent NO_2 effect. Controlling for other pollutants lowers the effect estimates at times, and at other times makes them statistically insignificant. • In some studies, NO_2, rather than PM, was found to be associated with asthma hospital admissions. An effect of NO_2 has been noted in most panel studies evaluating aggravation of asthma in children, showing a clear effect of NO_2 on the incidence of viral infections among asthmatics. • NO_2 levels are generally considered a reasonable marker of exposure to traffic-related emissions.
O_3	• O_3 at outdoor levels may induce either direct or indirect oxidative stress through inflammatory reaction to the respiratory tract. Short-term acute effects include respiratory symptoms, pulmonary function changes, increased airway responsiveness and airway inflammation. • Controlled chamber studies show changes in lung function and lung inflammation among young healthy adults when exercising. • O_3 affects pulmonary defence mechanisms because of impairment of mucociliary clearance, decreased macrophage activity and effects on circulating lymphocytes. O_3 may disrupt normal function of the airways and pulmonary immune system by suppressing or enhancing the host's immune responsiveness. Exposure to O_3 may increase bronchial responsiveness to allergens in subjects with airway allergy. • Combined evidence from time-series studies show positive associations between daily mortality and O_3 levels, independent of the effects of PM. An increase of 10 µg/m^3 in the 8-hour O_3 concentration is associated with a 0.3 to 0.5 per cent increased daily mortality. There is no clear evidence of a threshold for O_3. • O_3 exposure is significantly associated with an increase in morbidity. The most common health end-points are school absenteeism, hospital or emergency room admissions for asthma, respiratory infections, and exacerbation of chronic airway diseases. Children, elderly people, asthmatics and those with chronic obstructive airway diseases are more sensitive to O_3 exposure. • Epidemiological evidence of the chronic effects of O_3 is less conclusive.
CO	• After inhalation, CO diffuses rapidly across alveolar and capillary membranes and 80-90 per cent of the absorbed CO binds with haemoglobin to form carboxyhaemoglobin (COHb). The formed COHb reduces the oxygen-carrying capacity of the blood and impairs the release of O_2 from oxyhaemoglobin to extravascular tissues. This causes tissue hypoxia. In organs and tissues with high O_2 consumption such as brain, heavy exercising skeletal muscles and developing fetus. The toxic effects of CO are more prominent. • In healthy, non-smoking populations COHb levels are approximately 0.5-1.5 per cent. During pregnancy maternal COHb levels are elevated to 0.7-2.5 per cent. However, for car drivers, traffic policemen, garage attendants, tunnel workers and firemen COHb levels could be as high as 10 per cent.

	• Exposure to CO may contribute to cardiovascular mortality and the early cause of heart attack. • Patients with coronary artery disease are considered as most sensitive to CO exposure, with aggravation of angina occurring in patients at COHb levels of 2.9 - 5.9 per cent. • Increased COHb levels decrease the maximal exercise performance in a healthy population. • The fetus is extremely sensitive to CO exposure since the absorbed CO can diffuse through placental membrane.
VOCs	• General effects of exposure to VOCs include: o irritation to the eyes, nose and throat; o headaches; o loss of coordination; o nausea; and o damage to the liver, kidney and central nervous system. • Some VOCs can cause cancer in animals, and some are suspected or are known to cause cancer in humans. For example, benzene is known to cause leukemia.
PAHs	• It is not clear whether or not PAHs cause short-term health effects. • Possible long-term health effects caused by exposure to PAHs may include cataracts, kidney and liver damage and jaundice. Breathing large amounts of naphthalene can cause the breakdown of red blood cells. • Some people who have breathed mixtures of PAHs and other chemicals for long periods of time have developed cancer. • Some PAHs have caused cancer in laboratory animals when they breathed air containing them (lung cancer). • Benzo[a]pyrene is known to be a strong carcinogen (lung cancer) for humans.

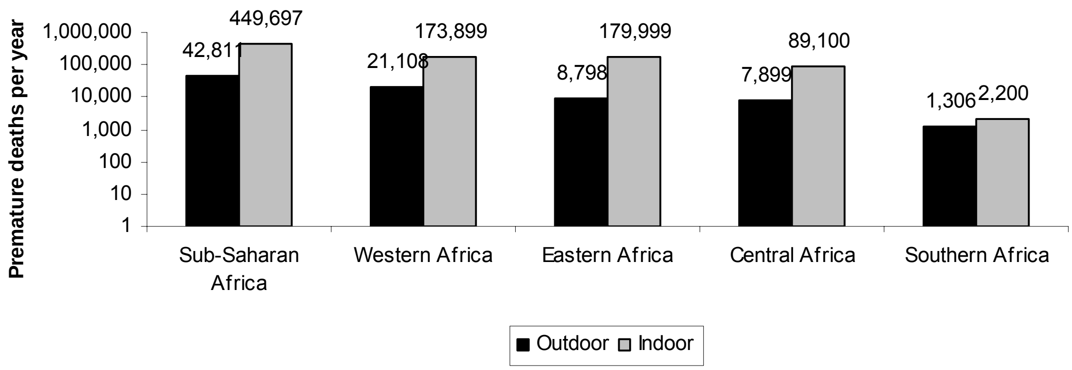


Figure 6.1: Premature deaths due to outdoor and indoor air pollution in SSA regions
Source: WHO (2006)

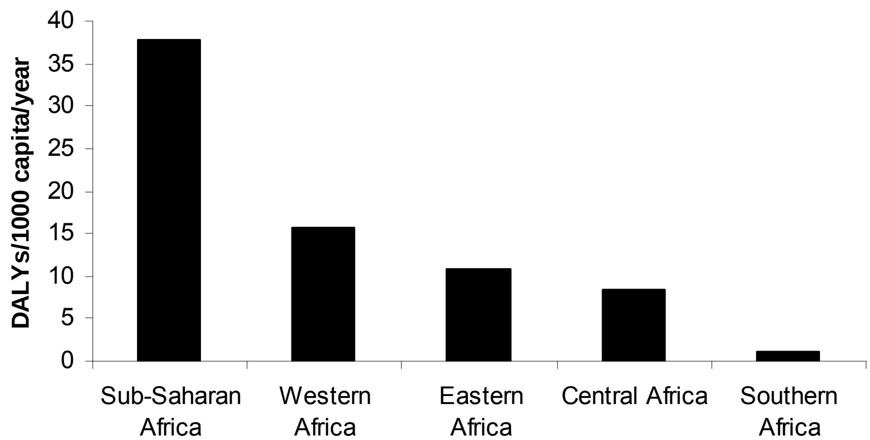


Figure 6.2: DALYs per 1000 capita and year due to outdoor and indoor air pollution in SSA regions
Source: WHO (2006)

6.6 Rapid Epidemiological Assessment

Rapid epidemiological assessment (REA) or rapid health assessment is a collection of methods that provides health information quickly, simply and at a lower cost than traditional epidemiological methods of data collection (Anker, 1991). The intention is to generate information quickly that is as reliable, accurate and useful as possible. The idea of REA is to modify and adapt standard epidemiological methods, techniques and approaches to be rapid, simple, low cost, with minimal data and human resource requirements. The objective is to identify critical issues, problems, hotspots of health impacts related to air pollution, help in priority setting and planning, and to communicate easily understandable results (von Schirnding, 2003). In REA methods it is inevitable, however, that some statistical precision will be sacrificed for the sake of speed and simplicity. In addition, REA methods cannot necessarily answer questions on the causal nature of the associations observed between air pollution and health impacts.

REA focuses on sampling methods that reduce the time and resources required to collect and analyse data from individuals, and methods for collection, organisation, analysis and presentation of information at the community level (Anker, 1991).

Table 6.4: Country-specific annual premature mortality due to air pollution and DALYs

Sub-Saharan Africa	Population [million]	Urban population in cities >100000 [%]	Urban population [million]	Deaths per year due to outdoor air pollution	Deaths per year due to indoor air pollution	DALYs/1000 capita/year
Angola	15.9	53	8.43	1,800	22,000	3
Benin	8.4	40	3.36	300	6,300	0.7
Botswana	1.8	57	1.03	9	200	0
Burkina Faso	13.2	18	2.38	1,100	21,100	1.7
Burundi	7.5	10	0.75	200	6,600	0.5
Cameroon	16.3	55	8.97	2,000	12,900	1.8
Cape Verde	0.5	57	0.29	9	99	0
Central African Republic	4.0	38	1.52	99	2,900	0.1
Chad	9.7	25	2.43	600	8,700	1.2
Comoros	1.0	37	0.36	99	100	0.2
Congo	4.0	60	2.40	500	700	1.3
Côte d'Ivoire	18.2	45	8.19	700	9,300	0.5
Democratic Republic of the Congo	57.5	32	18.40	2,900	41,700	0.9
Djibouti	0.8	76	0.61	200	99	3
Equatorial Guinea	0.5	39	0.20			0
Eritrea	4.4	19	0.84	200	2,800	1.1
Ethiopia	77.4	16	12.38	2,000	56,700	0.4
Gabon	1.4	84	1.18		200	0
Gambia	1.5	54	0.81	200	600	1.6
Ghana	22.1	48	10.61	600	5,600	0.4
Guinea	9.4	33	3.10	400	800	0.5
Guinea-Bissau	1.6	30	0.48	100	1,200	1.3
Kenya	34.3	21	7.20	600	13,000	0.2
Lesotho	1.8	19	0.34	99	400	0.4
Liberia	3.3	58	1.91	99		0.4
Madagascar	18.6	27	5.02	600	11,700	0.5
Malawi	12.9	17	2.19	600	13,300	0.7
Mali	13.5	30	4.05	700	16,900	1.2
Mauritania	3.1	40	1.24	200	2,300	1
Mauritius	1.2	42	0.50	99		0.4
Mozambique	19.8	35	6.93	900	9,700	0.6
Namibia	2.0	35	0.70	99	200	0.2
Niger	14.0	17	2.38	500	13,600	0.8
Nigeria	131.5	48	63.12	14,700	79,000	1.8

Source: WHO (2006)

Table 6.4: Country-specific annual premature mortality due to air pollution and DALYs (cont/)

Sub-Saharan Africa	Population [million]	Urban population in cities >100000 [%]	Urban population [million]	Deaths per year due to outdoor air pollution	Deaths per year due to indoor air pollution	DALYs/1000 capita/year
Rwanda	9.0	19	1.71	200	8,100	0.5
Sao Tome e Principe	0.2	58	0.09		99	0.9
Senegal	11.7	42	4.91	900	5,400	1.6
Seychelles	0.1	53	0.04			0
Sierra Leone	5.5	41	2.26	400	7,600	1.7
Somalia	8.2	20	1.64	300		0.4
South Africa	47.4	59	27.97	1,000	1,000	0.2
Sudan	36.2	17	6.15	3,700	4,400	1
Swaziland	1.0	24	0.24	99	400	0.3
Togo	6.1	40	2.44	200	4,100	0.4
Uganda	28.8	13	3.74	100	19,900	0.1
United Republic of Tanzania	38.3	24	9.19	1,000	27,500	0.4
Zambia	11.7	35	4.10	1,100	8,600	1.5
Zimbabwe	13.0	37	4.81	600	1,900	0.4
SSA	**750.2**		**254**	**42,811**	**449,697**	

Source: WHO (2006)

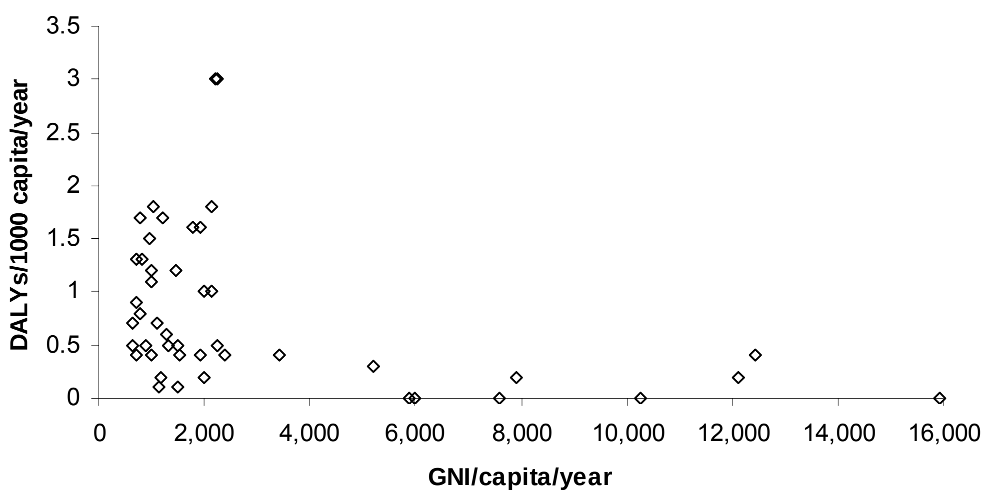


Figure 6.3: Relationship between GNI and DALYs for SSA countries

Source: WHO (2006)

An important objective is to obtain information on associations between exposures and health effects worthy of further investigation. Moreover, REA aims to minimise the probability of drawing wrong conclusions based on spurious associations.

Epidemiological information can be obtained at the level of the individual and at the level of the group. Studies at the level of the individual assessment require more resources than studies at the group level.

At the individual level assessment potential rapid study types are intervention, case control, cross-sectional and cohort studies. A **rapid intervention study** can be performed in a situation where a corrective action is tried to reduce exposure and health effects that are assessed before and after the corrective action. An example would be the reduction of the sulphur content of fuel to a lower value during a weekend and observation of SO_2 and sulphate concentrations and adverse health effects (e.g. respiratory symptoms, hospital admissions and excess mortality for respiratory-cardiovascular diseases) before and after the intervention (Hedley et al., 2002).

A **rapid case control study** can provide reliable results under special conditions when the diseased group (e.g. asthmatic children) and the non-diseased group are well identified, prior exposure of both groups can accurately be assessed, and confounding factors are properly addressed in the comparison of the two groups. A situation where there occurred a sudden release of a toxic pollutant would be a special application of this method. The study must be carefully conducted (Baltazar, 1991) to yield reliable results fairly rapidly. Case-control studies are, nonetheless, complicated with heavy demands for trained labour and logistical support. The selection of the diseased group, the difficulty in defining exposure, and the retrospective approach can lead to bias.

A **rapid cross-sectional study** investigates a number of samples (e.g. in different communities, under different exposures and assesses health symptoms and diseases via a questionnaire or door-to-door visits). This type of approach is of limited use with respect to identifying observed associations between exposure and health endpoints as causal since it is hard to assess the temporal nature of exposure and health outcome. For rare adverse health impacts a large sample would be needed enhancing the costs. Large areas within communities can be randomly sampled, and associations can be assessed by multiple regression analysis. This method has been extensively used in the clean air implementations plans of Germany (Schwela and Köth, 1993) and in the studies performed by Pope and Dockery (1996).

Cohort studies in which exposed and non-exposed subjects are followed up over a given period of time are normally costly. Exceptionally, if the health endpoint of interest is known to occur relatively quickly, thus limiting the necessary follow-up time, a **rapid cohort study** could be performed. Another example of a rapid cohort study could be an investigation of exposed and unexposed groups on the basis of historic hospital records, and following them up to the present and determining disease status (von Schirnding, 2003).

At the group level fairly **rapid study types** are ecological study, burden of disease study and time-series study.

An **ecological study** makes inferences about the relationship of exposures and health outcomes in individuals based on information obtained at the group level. This is reliable only if air pollution levels are fairly uniformly distributed. If this is not the case an apparent association observed at the group level may not hold on the individual level ('ecological fallacy'). An observed relationship between exposure and health outcome may be distorted by the fact that information on confounding factors (e.g. drug use, social variables) is frequently not assessed as it is only available at the individual level. Under certain circumstances (e.g. in the analysis of lung cancer rates in different parts of a region with differing known air pollution levels or source configurations) an ecological study can yield useful information (von Schirnding, 2003).

Related to ecological studies are **burden of disease studies** which use established exposure-response relationships for air pollution-related health outcomes in order to estimate the burden of premature mortality and morbidity in regions, countries or urban agglomerations. This method has been extensively applied by the WHO in estimates of the global and country-specific burden of disease (WHO, 2002, 2006). The method has been described in WHO (2003; 2004) and spreadsheets are downloadable from the internet (WHO, 2008). Only PM air pollution has been considered in these studies since the consideration of other compounds bears the risk of double counting. Under the provision that exposure response derived mostly from epidemiological studies in developed countries are transferable to developing countries this method is a low cost option to estimate the disease burden in a city, region or country.

The **Simple Integrated Model for Better Air Quality (SIM-Air)** described in Chapter 7 is a simple interactive tool for integrated AQM (Harshadeep et al., 2007). Among other calculations, the tool uses known exposure response relationships in analogy to the burden of disease approach to estimate health impacts associated with simulated air pollutant concentrations. SIM-Air is a low cost option that can be used among other issues to estimate health impacts in urban areas using an interactive system.

A **time-series study** associates short-term changes in health outcomes with changes in concurrent air pollution levels in an area over a given time period. Health endpoints may include daily mortality, hospital admissions for cardio-respiratory ailments, emergency department visits, outpatient visits, exacerbations in respiratory symptoms and diseases, lung function parameters. Confounding variables play a much smaller role in time-series studies since they are not expected to vary in the same way as air pollution levels (Pope and Dockery, 1996). Time-series studies are a low cost option to rapidly estimate the associations between air pollutant concentrations and heath endpoints.

6.7 Environmental Impacts

Air pollution has an effect on visibility. The visual range (or visibility) depends upon the transmission of light through the atmosphere and the ability of the eye to distinguish an object against its background. When the contrast between an object and the background approaches zero the object cannot be seen. On clean and clear days, the visual range may be up to 110 kilometres (kms). On moderately polluted and hazy days the visual range is reduced considerably to less than 20 kms, and still visible objects appear diffused. On very polluted and hazy days, visual range is reduced to a few kilometres, under extreme conditions even to a few tens of metres. The alteration of contrast or light intensity is due to the absorption and scattering of light by the atmosphere. In addition to these factors, meteorological factors can also affect visibility.

Air pollution has long been a significant source of damage to the corrosion of metals, cracking of rubber, soiling and eroding of building surfaces, deterioration of works of art, and fading of dyed materials. Injury to vegetation has been one of the earliest signs of air pollution, for example due to the effects of SO_2 emitted from smelters, and fluoride gases.

The mechanisms which result in damage include abrasion, deposition, direct and indirect chemical attack and electrochemical corrosion. Moisture, temperature, sunlight and air movement are the main factors that influence the attack rate of damaging pollutants. Deterioration of materials manifests itself and is observed in many ways. Building and artwork materials such as stone and mortar may be discoloured or leached away by pollutants. Demonstrations of such deterioration can be made by comparing photographs of buildings before and after cleaning, or by comparing photographs of the same artwork taken at different times.

Corrosion of metals is frequently detected by weight change, changes in the thickness or electrical resistance of a sample. Maintenance frequency is another measure to estimate corrosion losses. Protective coatings such as paints are affected by pollutants such as SO_2, O_3, hydrogen sulphide, tarry and greasy aerosols, and metal salts. Paint pigments provide hiding power and durability. Binder and additives hold the pigment to the surface. Both protect the underlying material from corrosion and weathering. Air pollution may limit both of these functions by damaging the protective coating and by exposing the underlying surface to attack. Typical examples for such attacks are discolorations of paints of buildings exposed to hydrogen sulphide. Another example is car soiling where cars are observed to be covered with mostly brown spots from iron particles that washing failed to remove.

The cracking of rubber is caused by O_3 and ultraviolet (UV) radiation. Both, UV radiation and O_3 attack the long hydrocarbon chains of the rubber with resulting loss of elasticity and other problems.

The effects of air pollutants on vegetation, crops, and forests include visible symptoms such as identifiable changes in the colour of the leaf. Visible injury is classified as acute or chronic. Acute symptoms are associated with short-term exposures to higher concentrations of air pollutants and usually appear within 24 hours after exposure. Chronic symptoms are associated with long-term or intermittent exposures to low concentrations of an air pollutant. However, repeated short-term exposure will cause physiological changes indicative of chronic symptoms.

Acute injury from air pollutants results in shrinking of the plant cell structure caused by loss of water. Tissue collapse and death may also be associated with chronic injury.

Reduction in growth caused by air pollutants is well established. In general, growth reductions have been related to visual injury symptoms. Major air pollutants such as O_3, oxidants and fluorides can affect plant reproductive structures and pollen germination and thus initiate genetic abnormalities and affect yield.

Air pollution effects on plant populations and communities may result in sensitive plants being replaced by more resistant plants. Effects are related to genetic variability, climatic factors before, during, and after exposure, and soil factors. A full understanding of air pollution effects on vegetation is difficult to gain because of the many factors that determine plant response.

Table 6.5 lists the major impacts which damage crops and forests and lead to a reduction in crop yield and quality, carbon reserves and forest decline, increased water stress, and reduction of nutrient availability. Reduced crop yields may cause local food shortages and famine and a change in food quality which may be detrimental to human health.

Table 6.5: Major impact of air pollution on crops and forests

Pollutant	Major sources	Major impacts	Scale of effects
Sulphur dioxide (SO_2)	Power generation; commercial and domestic heating	Visible foliar injury; altered plant growth; elimination of lichens and bryophytes; forest decline	Local
Nitrogen oxides (NO_x)	Power generation; transport	Altered plant growth; enhanced sensitivity to secondary stresses; eutrophication	Local
Ozone (O_3)	Secondary pollutant formed from NO_x and hydrocarbons	Visible foliar injury; reduced growth; forest decline	Regional
Suspended Particulate matter (PM)	Transport; power generation; industry; domestic heating	Altered plant growth; enhanced sensitivity to secondary stresses	Local
Fluorides	Aluminium manufacturing and smelting	Reduced plant growth; fluorosis in grazing animals	Local

6.8 Rapid Environmental Impact Assessment

Rapid Environmental Impact Assessment (REIA) is a quick, locally managed, low cost and participatory study method for gathering cross-sectoral baseline information about the impacts of air pollution from all sources on the urban environment. As it has to consider the environmental impacts of air pollution from all sources its scope goes beyond the scope of an Environmental Impact Assessment (EIA) which relates only to the process of estimation and evaluation of the environmental impacts of new projects in a participatory multi-stakeholder approach. Therefore the scope of the approaches of REIA has to be wider than that of the different approaches developed for EIA (e.g. the EU (EC, 1985) or the ADB (ADB, 2003)). In an EIA for an urban area the following tasks have to be considered.

1. Description of the **sources**, including their physical characteristics and air pollutant emissions.
2. Description of the **environment factors** likely to be significantly affected by the air pollution including, in particular, fauna, flora, soil, water, atmosphere, climatic factors, material assets, including the architectural and archaeological heritage, landscape and the inter-relationship between the above factors.
3. Description (a) of the likely **significant effects** (direct effects and any indirect, secondary, cumulative, short, medium and long-term, permanent and temporary, positive and negative effects) of the emission of pollutants on the environment resulting from the use of natural resources and the creation of waste; and (b) of the methods used to assess the effects on the environment.

4. Description of the **mitigation measures** applied or envisaged to prevent, reduce, and where possible, offset any significant adverse environmental effects.

The REIA is the attempt to solve these tasks using the rapid assessment methods described above for emissions, dispersion, and monitoring of air pollution. For an urban area this may still be a daunting task and one has therefore to look for simpler solutions.

The simplest REIA for industrial facilities and power plants would be to request facility operators to answer (yes/no) a checklist of screening questions regarding facility siting, operation and potential environmental impacts.

Facility Siting
Is the facility area adjacent to or within any of the following environmentally sensitive areas?

- Agricultural areas
- Protected Areas (e.g. natural parks; areas for protecting biodiversity)
- Buffer zones of protected areas
- Cultural heritage sites

Facility Operation
Does the facility dispose of:

- Equipment to clean flue gases?
- A routine inspection and maintenance programme?
- Environmental management plans?
- Emergency contingency plans?

Potential Environmental Impacts
Does the facility cause

- air pollution resulting from emissions from process equipment, emergency episodes, inadequate equipment maintenance, and poor operation?
- impacts of air pollution on agricultural areas?
- impairment of historical/cultural monuments/areas, and loss/damage to these sites?
- contamination of air from solid waste deposits?

This checklist would allow the environmental classification of a facility according to its potential environmental impacts. The set of the checklists from industrial facilities and power plants of a country, region or urban area would help estimate qualitatively the potential of environmental impacts in the area considered. This is a low cost option for obtaining this information.

Another opportunity of a low cost option using REIA is the assessment of potential O_3 impacts on agricultural crops. Without doubt, the most important threat in SSA is the reduction in crop yield due to O_3 exposure. The potential of O_3 impacts on crop yield can only be estimated when the regional exposure to O_3 is known. On the basis of regional emission inventories developed by APINA for SADC countries and a model developed by van Tienhoven et al. (2006), the regional exposure of crops to O_3 can be estimated. Application of this model could help determine the magnitude of the threat in other SSA countries. As the application of this model would avoid long-term crop yield losses and their causal association with O_3 exposure, it can be considered as a low cost option.

6.9 Implementation in Sub-Saharan Africa

A national health information system provides the necessary baseline data which allows estimates to be made of the health impacts due to air pollution. Without such a system, it is impossible to assess the contribution of air pollution to morbidity and mortality. The surveillance system can also establish or strengthen national and local epidemiological monitoring programmes that record morbidity and mortality cases associated with air pollution on a regular basis and use environment and health indicators following regional guidelines where they exist.

In order to define the range of air pollutants relevant to the protection of human health and the environment consultation of the relevant literature can be useful.

The adoption of national and local programmes for the monitoring of air pollution effects on human health and the environment can be used as a tool for protecting public health and the environment.

The establishment or strengthening of effective institutional arrangements to evaluate impacts of air pollution constitutes a good step forward in protecting public health and the environment. National and local information and training centres focused on the effects of air pollution on environment and health can serve this purpose.

A permanent recording system of the environmental and health impacts associated with air pollution, together with a standardised calculation of the social costs of air pollution on environment and human health can be used in cost-benefit analysis. The assessment of economic and financial impacts of air pollution on human health and environment will determine the economic costs of air pollution on society and the financial costs to different stakeholders. The socio-economic and environmental benefits from reduction of air pollution can made apparent.

Training specialised human resources and incorporating the topic of air pollution effects on environment and health in the general education of professionals is a step forward in public health protection.

An assessment of the environmental and socio-economic impacts of adopting new regulations on air quality helps to avoid unfavourable and costly decisions which have to be corrected when unexpected impacts occur.

National and local risk assessment programmes and risk assessments will help to achieve, in an appropriate way, large development projects that may have a significant impact on air quality but where unacceptable risk may be avoided by proper planning.

The establishment and implementation of a QA/QC process in public heath studies ensure that health assessment data are reliable and provide a sound basis for policy making. Many publications on public health studies (e.g. WHO) relating to air pollution exist which could be used to ensure suitable QA/QC and obtain data of known quality.

Wide dissemination of information gained from public health studies is an important means to inform all stakeholders, the public and decision makers.

The REIA checklist for industrial facilities and power plants provides a low cost option for identifying the potential impacts of these facilities.

Most important potential environmental impacts of air pollution in SSA are reduction in crop yields which may yield to food shortages and malnutrition. Since studies of environmental impacts are rare in SSA, research is therefore necessary to assess the magnitude of the threat. While SO_2 and fluorides only lead to very local impacts on crop yields, O_3 exposure can lead to regional impacts on crops. The modelling that has been performed in Southern Africa (Schwela, 2007) should be extended to other SSA countries.

6.10 Summary

Table 6.6 provides a summary of low cost tools for health and environmental assessment. Exposure to environmental pollutants is a problem of increasing concern due to a diversity of pollutants and the vast number of people at risk. Since individuals differ widely in genetic pre-disposition and physiological response, the effects of air pollution can sometimes be observed even when the pollution level is below the level indicated by air quality guidelines. Young and elderly, patients with cardio-vascular and pulmonary disease and workers in certain industries may be at higher risk due to their increased biological sensitivity and different exposure pattern. Only careful estimates of exposure can lead to meaningful assessments of health impacts.

Without a health information system, it is impossible to assess the contribution of air pollution to morbidity and mortality. The system can be expanded to report morbidity and mortality cases associated with air pollution on a regular basis. The use of rapid assessment techniques for epidemiological studies and evaluation of the data of the surveillance system is a starting point for estimates on the impacts of air pollution on human health and their social costs. Social costs of air pollution can be used in cost-benefit analysis comparing costs of control and costs of avoided health and environmental impacts.

The design of epidemiological health studies and their use in rapid health impact assessment includes: cross-sectional; ecological; cohort; case-control and time-series studies.

The local and national burden of disease due to air pollution should be estimated, including the consideration of vulnerable sub-populations such as women and children, the poor, the elderly and the diseased.

Use of rapid methods for health impact assessment may lead to useful estimations of health impacts. Uncertainties of rapid assessment methods should be carefully considered.

REIA checklists for industrial facilities and thermal power plants allow the potential environmental impacts of these facilities to be identified.

O_3 is presently the most important compound with respect to environmental impacts in SSA as it is a threat to crop yields which may result in significant crop reduction and consequent malnutrition of people.

Economic valuation of impacts is necessary for cost-benefit analysis in air quality management.

Table 6.6: Summary of low cost tools for health and environmental assessment

Objective	Low Cost Option	Description	Examples
The objective for health and environmental assessment is to establish and/or strengthen national and local programmes which monitor the health and environmental impact of air pollution in a harmonised way. This includes: Undertaking long-term studies of health and environmental impacts due to air pollution; Strengthening institutional capability; Assessing of health, environmental and economic impacts of air quality; Augmenting and disseminating information on health and environmental impacts; Ensuring spatial and time representativity of monitoring sites for actual exposure of humans and the environment.	Rapid Health Assessment Studies	Rapid epidemiological assessment methods include: Use of the WHO environmental burden of disease approach and applying known exposure-response relationships for air pollution impacts to estimate mortality and morbidity. This approach requires knowledge of exposures (air pollutant concentrations and durations). Use of the SIM/Air model to estimate the health impacts on the basis of modelled emissions, simulated concentrations and known exposure-response relationships. Undertaking elementary time-series studies of mortality and morbidity over a time period and correlating health impacts with air pollutant concentrations over the same time period.	The WHO has estimated the global burden of disease due to environmental factors - outdoor air pollution, indoor air pollution, lead, climate change and estimated the corresponding DALYs. Similar estimations were made for each country. The SIM/Air model uses the WHO exposure-response relationships to estimate the number of premature deaths, incidence of diseases. The model has been applied in Hyderabad, India. Time-series studies have been performed in many developed and some developing countries. Cross-sectional studies have been performed in many developed and some developing countries.

Table 6.6: Summary of low cost tools for health and environmental assessment

Objective	Low Cost Option	Description	Examples
		Undertaking elementary cross-sectional studies of the prevalence of health impacts at high, medium and low exposures and correlating them with corresponding air pollutant concentrations considering confounding variables. Rapid Environmental Impact Assessment Studies include: Checklists for assessing the potential environmental impact of industries and power plants, especially on agriculture, protected sites, forests and biodiversity. Estimations of the potential threat of O_3 pollution to reducing agricultural crop yields.	Such checklists are being used by ADB in REIA to categorize the environmental hazard of new projects for chemical-based industrial facilities, mining industries, power plants, roads and highways, and urban development. CSIR has developed a dispersion model for such estimates and applied it to estimate O_3 concentrations and their potential impact on crop yield in SADC countries.

Chapter 7

Policy Instruments

7.1 Objective

The objective of policy instruments is to include and/or strengthen the concept of AQM in relevant policies and legislation of SSA cities and countries. This includes:

- increasing the level of government commitment to AQM policies and their enforcements;
- strengthening co-ordination and integration of AQM in all sectors;
- improving collaboration among different agencies responsible for AQM;
- increasing capacity to implement and AQM legislation;
- strengthening appropriate review mechanisms of AQM;
- harmonising regional regulations on emission sources and transboundary pollution;
- harmonising as far as feasible regional emission and air quality standards and update them;
- increasing stakeholder participation in the formulation and implementation of AQM policies; and
- strengthening public awareness.

7.2 Situation

Strategies to achieve better air quality in SSA countries should use a set of policy instruments which are regulated in specific AQM legislation. A number of SSA countries (e.g. the Central African Republic, Democratic Republic of the Congo (Congo-Kinshasa), Djibouti, Equatorial Guinea, Eritrea, Guinea-Bissau and Rwanda) have not yet introduced environmental legislation. In some countries such as Cape Verde, Chad and Côte d'Ivoire environmental protection is laid down as an objective in their Constitution with no further legislation being issued. Most other SSA countries have issued Acts on the protection or conservation of the environment and its management. Specific legislation for AQM exists only in a few countries (e.g. Botswana, Nigeria, and Zimbabwe). Table 7.1 shows the main legislation in SSA countries.

Table 7.1: Environmental legislation in SSA countries

Country	Environmental Legislation	Year
Angola[1][2]	Constitution Law - Article 24 – Protection of the Environment Fundamental Law of the Environment of the Republic of Angola	1992
Benin	Environmental Law	1999
Botswana	Atmospheric Pollution Prevention Act Environmental Impact Assessment Act No 6 Law on Mines and Minerals	1971 2005 1977
Burkina Faso	Environment Act Law on the Operation of Mines Law on Public Health	1997 1997 1994
Burundi	Environment Act No 1/010	2000
Cameroon	Environment Act	1996
Cape Verde[3]	Constitution – Article 7–1j – Protection of the Environment	1992
Central African Republic[4]	No environmental legislation exists apart from a law on forest conservation	NA
Chad[5]	Constitution – Article 48 - Protection of the Environment	1996
Comoros[2]	Environmental Action Plan	
Republic of the Congo (Congo-Brazzaville)	Legislation relating to air pollution is diluted in many partly overlapping texts among the environment, energy, and transport sectors	NA
Côte d'Ivoire[6]	Constitution – Article 28 – Protection of the Environment	2007

[1] Republic of Angola 2008 The Constitution Law – Fundamental rights and Duties. http://www.angola.org.uk/law_rights_duties.htm
[2] IIED/WRI/IUCN 1998 A Directory of Environmental Impact Assessment Guidelines. http://books.google.co.uk/books?id=SVsEYo9h924C&pg=PA56&lpg=PA56&dq=Eritrea+environment+legislation&source=web&ots=K7Zh47EdYV&sig=L-Z59cLIvNU0rX6O5WeNhTDjhns&hl=en&sa=X&oi=book_result&resnum=1&ct=result#PPP1,M1
[3] The Constitution of the Republic of Cape Verde 1992. http://capeverde-islands.com/cvconstitution.html
[4] The World Law Guide 2008 Legislation Central Africa. http://www.lexadin.nl/wlg/legis/nofr/oeur/lxwecaf.htm
[5] Constitution of the Republic of Chad 1996 http://www.chr.up.ac.za/hr_docs/constitutions/docs/ChadC%20(english%20summary)(rev).doc
[6] Constitution de la République de Côte d'Ivoire 2007. http://droit.francophonie.org/df-web/publication.do?publicationId=235&sidebar=true

Table 7.1: Environmental legislation in SSA countries (cont/)

Country	Environmental Legislation	Year
Democratic Republic of the Congo (Congo-Kinshasa)	A framework law on environmental management and AQM in particular has yet to be promulgated.	NA
Djibouti[7]	Enforcement of conservation and environmental legislation is largely non-existent	NA
Equatorial Guinea[8]	None apart from control on fish net mesh size	NA
Eritrea	Legislation has not yet been drawn up	1988
Ethiopia	Constitution of Federal Democratic Republic of Ethiopia Pollution Control Proclamation Ethiopian Impact Assessment (EIA) Proclamation	1995 2002 2002
Gabon	Environment Act, Chapter 4	1993
Gambia[9]	National Environmental Management Act	1994
Ghana	Act 490, Environmental Agency Act	1994
Guinea[10]	Law on the Protection and Valuation of the Environment Special regulations to manage air quality do not exist.	1989
Guinea-Bissau	No environmental legislation has been yet enacted	NA
Kenya[11]	Environmental Management and Co-ordination Act	1999
Lesotho[12]	The Constitution of Lesotho, Article 36 – Protection of the Environment No specific environmental legislation is issued apart from Forestry and Tourism Acts	1993
Liberia[13]	Constitution of Liberia Article 7 Minerals and Mining Law Environment Protection Agency Act Environment Protection and Management Law	1986 2000 2002 2002
Madagascar[14]	Law No. 5 – Air Protection Management	2000

[7] African Bird Club 2008 Djibouti – Conservation.. http://www.africanbirdclub.org/countries/Djibouti/conservation.html
[8] UN System-Wide Earthwatch 1998 Equatorial Guinea – Environmental Legislation. http://islands.unep.ch/CPK.htm
[9] All Gambian.net 2007 Environmental Policy and Politica in the Gambia. http://www.allgambian.net/NewsDetails.aspx?id=146
[10] The World Law Guide 2008 Legislation Guinea. www.lexadin.nl/wlg/legis/nofr/oeur/lxwegui.htm
[11] The World Law Guide 2008 Legislation Kenya. www.lexadin.nl/wlg/legis/nofr/oeur/lxweken.htm
[12] The World Law Guide 2008 Legislation Lesotho. www.lexadin.nl/wlg/legis/nofr/oeur/lxweles.htm
[13] UNEP 2004 Desk Study on the Environment in Liberia. http://postconflict.unep.ch/publications/Liberia_DS.pdf
[14] The World Law Guide 2008 Legislation Madagascar. www.lexadin.nl/wlg/legis/nofr/oeur/lxwemad.htm

Table 7.1: Environmental legislation in SSA countries (cont/)

Country	Environmental Legislation	Year
Malawi	National Environmental Policy – Environment Management Act	1996
Mali	Environment Act Pollution and nuisance control	1998 2000
Mauritania[2]	Law No. 45 – Environmental Law	2000
Mauritius	Environmental Protection Act	1991
Mozambique	Constitution Article 72 - right to a balanced environment Environment Act	1990 1997
Namibia[2]	The government is working on an Environment Act to be promulgated by end 2008.	2008
Niger[15]	Environmental Law	1998
Nigeria	Decree No 58 – Federal Environmental Protection Agency National Guidelines and Standards for Environmental Pollution Control in Nigeria	1988 1991
Rwanda	No environmental legislation has been enacted yet	NA
São Tomé e Principe[16]	Law No. 10/99 Fundamental Environment Law	1999
Sénégal	Environment Act	2001
Seychelles[17]	Environmental Protection Act	1994
Sierra Leone	National Environmental Policy National environmental Action Plan	1994 1995
Somalia[2]	No environmental legislation has been issued	NA
South Africa	Environment Conservation Act	1982
Sudan[18]	Sudan Constitution Environmental Act	1998 2001

[15] The World Law Guide 2008 Legislation Niger. www.lexadin.nl/wlg/legis/nofr/oeur/lxwenge.htm
[16] Legislação Ambiental E do Saneamento do Meio 1999. www.parlamento.st/Legisl/leg%20Amb_sanea_meio/Frames_legisl_amb_s_meio.htm
[17] IIED/WRI/IUCN 1998 A Directory of Environmental Impact Assessment Guidelines. http://books.google.co.uk/books?id=SVsEYo9h924C&pg=PA56&lpg=PA56&dq=Eritrea+environment+legislation&source=web&ots=K7Zh47EdYV&sig=L-Z59cLIvNU0rX6O5WeNhTDjhns&hl=en&sa=X&oi=book_result&resnum=1&ct=result#PPP1,M1
[18] Eljack N 2004 Urban air pollution in Sudan: A case study of Greater Khartoum. BAQ 2004

Table 7.1: Environmental legislation in SSA countries

Country	Environmental Legislation	Year
Swaziland	Environment Management Act	2002
Togo	Constitution Article No. 41 Environment Act Hydrocarbon Act	1992 1998 1999
Uganda	No legislation on air pollution management has yet been promulgated	NA
United Republic of Tanzania	Act No. 20 - Environmental Management Act	2004
Zambia	Environmental Protection and Pollution Control Act Statutory Instrument No. 141	1990 1996
Zimbabwe	Atmospheric Pollution Prevention Act (APPA) APPA Amendment Act 20:03 Atmospheric Pollution Prevention Regulations for Smoke Control Hazardous Substances and Articles Act Environmental Management Act (Chapter 20:27)[19]	1971 1996 1999 1977 2006

The Environment Acts introduced in SSA countries cover air pollution. The Environment Acts are often complemented by regulations and rules which specify fuel parameters, emission standards and air quality standards. The majority of SSA countries address AQM in an unsystematic way. For example, out of the 27 SSA countries examined by Schwela (2007), only sixteen countries had set fuel specifications for gasoline and fourteen for diesel, only five countries had introduced emission standards for vehicles and eight had set air quality standards.

Legislation and regulations in SSA countries are far from harmonised. Legislation in the fifteen SADC region countries (in italics in Table 7.1) is not harmonised despite harmonisation being part of the objectives formulated in the Declarations of Harare (1998) and Maputo (2003) on regional air pollution and reiterated in the Draft Lusaka Agreement (UNEP, 2008).

[19] The World Law Guide 2008 Legislation Zimbabwe. www.lexadin.nl/wlg/legis/nofr/oeur/lxwezim.htm

Harare Declaration (1998)	Maputo Declaration (2003)
Harmonised and strengthened legislation. Appropriate incentive structures. Awareness and education. Improved information availability and accessibility to information use and development of improved technologies. Assess and analyse the origin and causes, nature, extent and effects of local and regional air pollution. Identify appropriate financial resources.	Assess and analyse the origin and causes, nature, extent and effects of air pollution. Develop and/or adopt strategies to prevent and minimize air pollution. Building up standardised methodologies to monitor pollutants of concern (sulphur dioxide, carbon monoxide, nitrogen oxides, ozone, particulate matter, volatile organic compounds, persistent organic pollutants, lead and other heavy metals). Stakeholder participation. Integration of scientific information in national/regional air pollution policy decisions. Harmonise among the states national legislation and air quality standards. Establish mechanisms and procedures for a shared regional atmospheric emissions inventory. Enhance capacity of African institutions. Securing assistance from funding agencies. Promote national reporting systems. Draw up and implement national and regional action plans for transboundary air pollution. Promote the practice of cleaner production.

Most countries address AQM in an ad hoc fashion. Out of 27 SSA countries (Schwela, 2007), only Madagascar appears to have developed a full-fledged AQM system addressing revision of legislation, emissions, dispersion, air pollutant concentrations, control measures, impacts and cost-benefit analysis. Ghana and Tanzania are on the way to developing an AQM system. Benin's legislation, by referring only to mobile sources, disregards industrial sources, uncontrolled fires, waste deposits and transboundary air pollution. Botswana's air pollution legislation is thirty-seven years old and covers only industrial sources and disregards all other sources (Schwela, 2007).

In the Republic of the Congo (Congo Brazzaville), the legislation relating to air pollution is diluted in many partly overlapping texts among the different sectors of the environment, energy and transport. Guinea, Liberia, the Democratic Republic of the Congo (Congo-Kinshasa), Rwanda and Uganda have no official legislation for regulating and managing air pollution. Regulations on fuel parameters for petrol and diesel do not exist. In view of the substantial PM concentrations and their potential health impacts, the adoption of legislation regulating AQM is urgent. Kenya is in a similar situation since a comprehensive urban AQM programme is lacking.

In Nigeria, few activities in relation to AQM have taken place and ad hoc measures are adopted. Togo's two policies on energy development and transport and the strategy to combat air pollution tend to be ad hoc measures rather than integrated policies. The implementation of these policies has not yet started due to lack of funding and logistics.

Zambia's legislation aims to control pollution but is not legally binding for maintenance, monitoring and support of air quality. As a consequence, monitoring is not performed by the government but rather delegated to industry with respect to their own industrial air emissions. Vehicle emissions are consequently not really controlled.

7.3 Strategies for Air Pollution Reduction

AQM is based on appropriate legislation, implementation and enforcement. Strategies to reduce air pollution and achieve better air quality in SSA cities should use a mix of different policy instruments which are regulated in specific air pollution legislation.

There is a wide range of policy instruments and approaches available to prevent and/or control air pollution. In selecting the suitability of a particular policy instrument a range of factors should be taken into consideration (See Table 7.2).

Table 7.2: Factors considered in the implementation of strategies to prevent and/or control air pollution

Factor	Consideration
Technical	Effectiveness Sustainability under local conditions
Administrative	Feasible with the legal and administrative framework Enforceability
Economic	Economic Costs and benefits
Social	Equity in sharing of costs and benefits Culture of compliance
Political	Public support Stakeholder pressure

Policy instruments are more effectively implemented when prepared as mutually supportive actions advocated by key stakeholders. Resources are also more likely to be available when they are linked to a clear strategic framework and are part of a mutually supportive package of interventions. In considering the use of a range of different policy instruments the following issues should be considered:

The likelihood of success and major risk factors of each implementation option

In selecting the options for implementation, it is important to use appropriate tools to estimate the environmental benefits of options. Interactive tools that can be used are emission assessment tools, dispersion models and decision support systems for assessing air quality near polluting activity sectors.

Before selecting implementing strategies, it is essential to predict their effectiveness and efficiency in addressing air quality, as well as the potential for any unintended economic and social consequences. High priority, inexpensive, and easily implementable strategies should be used first, with complex problems requiring considerable resources to be introduced at a later stage.

The social and economic costs and benefits for key stakeholders

The implementation of strategies to reduce air pollution may have adverse and unintended consequences for some stakeholders. For example, the conversion of parts of city centre to pedestrian areas may reduce vehicle emissions, but these measures can have some adverse economic and social consequences for local businesses and residents. Economic instruments that make polluting activities more expensive may adversely affect poor groups in society while having little impact on the behaviour of wealthier groups.

The policy reforms and institutional strengthening to support implementation

The implementation of strategies to reduce air pollution often requires partnerships among government and non-government agencies to address issues involving cleaner fuels, transport, energy, planning and economic development. The success of these strategies may not be a high priority for all partners. Changes to regulations (e.g. fuel regulations) and amendments to other legislation and changes in institutional arrangements may be needed to ensure continued institutional support for implementation. Institutional strengthening may be required in the form of access to resources and training in new procedures.

The long-term environmental targets as well as interim milestones to assess progress towards implementation of strategies

Some strategies to improve air quality may take considerable time to be successful, for various reasons, including technical barriers, lack of resources and training and social resistance. In these cases, a phased, step-by-step implementation may be required. The strategy should have a clear time frame for the different phases of implementation. The progressive implementation of Euro vehicle emission standards in most countries of Asia is an example of this approach (ACFA, 2005) which could be followed by SSA countries. A phased implementation can provide a long-term strategy to address complex issues, but providing results in the short-term.

Positive short-term results enhance political support and resources for implementation of the strategy. To manage a long-term strategy it is important to monitor progress through the different phases of implementation, for example, with progress reports and feedback on targets, etc. This enables the tracking of progress and enables evaluation and review of important decisions. The indicators and targets selected should be clearly related to the successful implementation of the strategy, and should be relatively simple to monitor, quantify, and verify.

For example, the decrease in the monitored levels of SO_2 in urban air can be a good indicator of the impact of a strategy to install desulphurisation units in power plants and industrial facilities. Similarly, a decrease in the observed levels of fine $PM_{2.5}$ in urban air can be a good indicator of the impact of a strategy to lower the sulphur content of diesel and fuel oil.

Indicators to assess progress

Indicators to assess progress achieved in implementing the strategy include the reduction of:

- concentration levels and exposures;
- the air pollution related burden of disease;
- emitted amounts of harmful substances;

- effects on the environment;
- energy used by all stakeholders;
- emission of greenhouse gases; and
- the increase in energy efficiency.

Most strategies aim as far as practicable to follow the Polluter Pays Principle, whereby those responsible for emissions bear the full costs of monitoring and controlling those emissions.

The ease of implementation of the strategy

While sophisticated implementation strategies, which may have proved effective in other countries, may seem attractive, it is usually preferable to select implementation strategies that are achievable within the technical, social and economic constraints of the implementing agency with whatever institutional strengthening is required. These may be phased-in with increased sophistication, if necessary, as experience is gained over time. Such implementation strategies may need to be amended or added to in response to specific local situations, for example, adaptation to local air quality problems, local opinions, and locally sustainable technologies and experience.

There are many types of instruments available to policy makers to address issues of pollution prevention and pollution control. Each instrument has particular strengths and weaknesses, and a combination of instruments usually offers the best approach to most air quality issues. In practice, a mixture of policy instruments to prevent or control air pollution is used these are based on a particular regulatory approach adopted to control emissions from particular sources.

7.4 Regulatory Approaches

Laws and regulations are at the heart of AQM strategies. The traditional approach to the implementation of AQM strategies has been the command and control approach. Other approaches include self regulation, economic instruments or a mixture of co-regulation and voluntary agreements as well as education and information. Table 7.3 provides an overview of the different types of environmental regulation available.

Command and Control

Command and control is the backbone of air quality regulation in many countries. It has been relatively successful in addressing some air quality issues, especially the implementation of emission standards (e.g. Euro emission standards for mobile sources). Large, reputable organisations concerned about their public image usually comply with regulations. Regulation has been less successful in controlling the behaviour of small and medium sized organisations that have sometimes responded by concealment. It also requires regulators to have a comprehensive and accurate knowledge of the workings of the industry they are trying to control, as well as the specialist skills required of regulators operating in a legal environment. These high levels of knowledge and skill are not always available within the regulation system of developing countries. To be effective, regulatory approaches require a credible deterrent threat. Regulation places considerable pressure on the regulator to perform to the standard required. Where there are inadequate resources to monitor, inspect and ensure compliance no credible deterrent threat usually exists if an organisation is not concerned about its public image. Enforcement measures include the imposition of substantial and punitive fines, public exposure where an organisation is concerned about its public image, threat of prison sentences for Directors, requirements for expensive remedial work including monitoring, pollution control, site remediation or withdrawal of licences to operate.

Table 7.3: Types of environmental regulation

Type	Description	Example
Command and control	Issue of licences, setting of standards, checking for compliance with standards, sanctions for non-compliance	Air pollution control regulations Government monitoring Emission standards Enforcement policies
Economic instruments	Use of pricing, subsidies, taxes, and charges to production and consumption patterns	Load-based emission charges Tradeable emission permits Differential taxes True cost pricing of resources
Co-regulation and voluntary initiatives	Adoption of rules, regulations and guidelines, negotiated within prescribed boundaries Voluntary adoption of environmental management measures	National registers of pollution emission inventories Environmental management systems
Self-regulation	Self-imposition of rules and guidelines and environmental audits by industry groups	Industry codes of practice Self-audit within industry groups Emission reduction targets
Education and information	Education and training Community right-to-know Corporate reporting programmes	Education, training and information programmes Pollution inventories Corporate sustainability reports

Source: WHO (2000), Bradfield et al. (1996)

The regulatory approach has worked well in many cases such as measures introduced to reduce emissions of SO_2 and coarse particles, and to eliminate the use of lead in petrol which was achieved in SSA countries on 1 January 2006. The considerable success in improving air quality in Japan since the late 1960s was largely achieved through command and control (Hashimoto, 1989). In some cases the use of regulations can be cheaper than other instruments. A comparison of options for controlling SO_2 emissions in Hong Kong found that a ban on the importation of high sulphur fuels by regulation was the best option for reducing SO_2 emissions. The cost of compliance monitoring made the costs of flue gas desulphurisation or the use of market based instruments more expensive than a ban on high sulphur fuels (Barron, 1995). The use of regulations to prevent the use of high sulphur fuels and to promote energy conservation may be less expensive for developing countries than some other options (Pearce, 1996).

The command and control approach can be rigid, with the potential for arbitrary decisions. It tends to focus on end-of-pipe solutions instead of pollution prevention approaches. While it may establish requirements for emissions performance standards, it provides no incentive for sources to minimise emissions, provided that their licence conditions are met. It provides little encouragement for continuous improvement. This approach usually ignores equity principles and costs as it may require highly expensive best available technology for new sources, while existing sources may continue to pollute at much higher levels provided the conditions of their licences are met.

Self-Regulation

The reform of regulations in the last two decades in many countries around the world has reduced the dependence on the regulatory approach, especially among developed countries (World Bank, 2000). The trend is towards increased use of a policy mix, including other policy instruments. One approach is self-regulation. Self-regulation is the adoption by an organisation or group of a system of practices with the aim of regulating the behaviour of the members. Self-regulation is commonly practiced by industry groups where members share similar environmental issues (Gunningham and Grabosky, 1998).

Some industry groups, for example, the chemical industry or petroleum industry groups, are more familiar than regulators with current best practice within their own industry, and they are able and willing to set codes of practice, industry standards and targets to be achieved by members of their industry groups. Individual organisations conduct self-monitoring of compliance, and compliance with the code is subject to audit. The Responsible Care programme operated by the chemicals industry in many countries is a good example of self-regulation (ICCA, 2006). It has the potential to be flexible, responsive to market conditions, efficient, and it requires less government intervention and thereby costs to the taxpayer, than command and control.

Unfortunately, the theory does not match the practice of self-regulation. In many cases the standards are weak, monitoring is superficial, and enforcement is ineffective and not transparent (Gunningham and Grabosky, 1998). Where self-regulation operates effectively, governments maintain a watching brief to a greater or lesser extent. Where self-regulation regimes are considered by the public or government to be failing to deliver outcomes in the public interest, the regimes may in part or in whole be replaced by government regulations (Gunningham and Rees, 1997).

Economic Instruments

A variety of economic instruments to reduce air pollutant emissions are available to policy makers in developing countries (Rietbergen-McCracken and Abaza, 2000; Breithaupt, 2001). The Organization for Economic Cooperation and Development (OECD) argues that economic instruments provide the best means of internalising the negative environmental externalities (OECD, 2001). It claims that the costs of environmental protection should be imposed on the polluter (i.e. the polluter pays principle), instead of being subsidised by governments, enabling the costs of environmental protection to be incorporated into prices and markets.

Economic instruments have a role in encouraging good performance and penalising poor performance. The cost must be set at a level that provides an incentive for industry to reduce emissions as far as practical, while remaining competitive in the marketplace (OECD, 2001). A powerful economic instrument for air quality improvements is economic pricing policy. It has been estimated that direct energy subsidies in developing countries total nearly US$ 230 billion each year (El-Ashry, 1993). Reducing subsidies for energy use encourages energy conservation, reduces emissions from power stations, and frees investment for other purposes such as less polluting technologies (Hall, 1995).

Economic incentives for AQM must be designed according to clearly defined, specific goals. To be effective and cost-minimising, economic incentives must be tailored to the conditions of the specific market, and also to the pollutant, or pollutants, which are being addressed.

In the control of emissions from industry and the energy sector, emission permits allow for the introduction of environmental fees when the emission limit is exceeded. If the fee is high enough, there will be a clear incentive for the industry or power plant to implement cleaner technologies or introduce air pollution control equipment. Or the authorities can close the plant if emission limits are repeatedly exceeded. However, if the fee is disproportionately low compared to the cost of reducing emissions, there is a risk that the companies will prefer to pay the fees rather than to implement air pollution control.

Another market oriented approach to reduce emissions as part of an AQM strategy involves the use of a system of cap-and-trade of emission permits. In this system, the regulating authority quantifies the total mass of emissions to be permitted in an area and issues the equivalent number of tradable emissions entitlements. These tradable permits can be freely bought and sold. This system has the potential to achieve government policy objectives at the lowest cost to industry, and in some cases to government. A comparison of command and control and market-based incentives in Santiago, Chile, found that flexible market-based incentives allowed substantially higher reductions in emissions to be achieved for the same expenditure as traditional regulatory approaches (O'Ryan, 1996).

Economic incentives could be the introduction of a ban or fee for open waste burning. Obviously, alternative waste disposal systems should be available before such an incentive to avoid waste burning can be introduced.

Compared to direct regulation, incentive-based regulation may lead to more cost-effective pollutant reduction measures. Through economic incentives, the state will have to spend a minimum of resources (that would otherwise have been spent on regulation and enforcement), and the market mechanism may determine the most cost-effective control technology.

Co-Regulation and Voluntary Instruments

Co-regulation should consist of the implementation of negotiated agreements between individual organisations and regulators including environmental performance targets and strategies; documented product stewardship responsibilities; and independent third party verification. It should also be underpinned by the requirement that the regulator takes action when circumstances require it.

A number of countries have introduced the implementation of voluntary negotiated agreements between individual companies and regulators. This is a jointly agreed systematic approach to environmental management including performance targets and strategies, product stewardship responsibilities and external verification to achieve "beyond compliance" goals. This also needs to be underpinned by the capacity of the regulator to take enforcement action when circumstances require it.

Co-regulation is a model used in the US, the Netherlands, and elsewhere, to enable regulators to audit the performance of those companies with very good environmental performance. It is implemented through negotiated agreements to meet performance targets and objectives. For the regulator it enables proportionately more time and resources to be focused on poor environmental performers and the command and control regulation of those organisations requiring this direct form of regulation.

An example of co-regulation is the 2004 Agreement between the Singaporean Government and the Transport Sector to encourage owners of buses, taxis and other commercial vehicles to make an early switch to either Euro IV diesel vehicles or CNG vehicles before the implementation of Euro IV standards on 1 October 2006 (MEWR, 2007). Another example is the phase-out agreement between Australian Government and Australian Retailers Association to phase-out plastic bags by 2008 (ALGA, 2005).

A third example is the Charter on the Corporate Responsibility for Environmental Protection (CREP) which was agreed between the Indian government and industry. The purpose of the CREP is to encourage industry to go beyond regulatory requirements for compliance and improve the environmental performance through use of cleaner technologies, reduction of air pollutant emissions, in-plant process control and waste minimization (CPCB, 2008).

Education and Information

Effective education and information communication tools raise awareness of air quality issues, and can be important in changing behaviour and attitudes in ways that cannot be addressed by other instruments. The successes of AQM strategies have often involved action at all levels in the community. In many cases it is local level response to complaints from citizens that triggers action by the central government. Actions to control air pollution have sometimes been only possible by establishing communications between local communities, local government and the relevant national government agency responsible for air quality issues. There are numerous examples available of this approach (ADB, 2001; Daniere and Takahashi, 2002). Two-way communication between local communities and those responsible for AQM is essential; it requires use of many techniques to be successful (Murray, 1997).

7.5 Implementation of Strategies

AQM strategies to address outdoor air pollution can be implemented in five areas: transport, industry, area, transboundary and climate change. The following sections briefly examine various strategies for managing air quality in each of these areas. The key to implementation is an assessment of the priorities of the issues associated with emissions in each area. The strategies to reduce air pollution should address the priority issues and pollutants. In most cases, the emissions with the greatest health effects should be targeted first.

Industry Sector

To implement strategies to reduce urban industrial emissions, it is important to have adequate information on the type of emissions from these industries, tendencies in emissions and effectiveness of actions to reduce these tendencies, and priorities. Most of this information should be available from emissions inventories. The main strategies for addressing industrial pollution are the promotion of cleaner production, emissions reduction by industry, land use planning and zoning.

Promoting cleaner production

Cleaner production and eco-efficiency aim to increase the efficiency of industrial processes and reduce consumption, prevent pollution, reduce wastes at source and minimise risks to people and the environment. Cleaner production is a way to achieve both environmental protection and economic benefits by better managing the production process, often saving energy and materials. In the case of AQM, the main cleaner production successes have been achieved by improving the quality of fuels, for example by reducing sulphur content or requiring cleaner fuels such as gas. Although cleaner production is the most sustainable solution, some end-of-pipe solutions are still necessary to address industrial air pollution. However, prevention of pollution by use of cleaner fuels and the adoption of new technologies that avoid emissions is generally less expensive than end-of-pipe techniques to reduce pollution, if the costs of the effects of pollution on health and the environment are included (APMA/CAI-Asia, 2004). Fuel taxes have been successfully used in many countries to provide economic incentives to use cleaner fuels and reduce the use of polluting fuels (World Bank, 1999).

Promoting emissions reduction in industry

The promotion of the reduction of industrial emissions may involve:

- setting priorities by focusing on emissions from the major emission sources;
- requirements for use of cleaner fuels;
- requiring the use of best available technology: policies need to focus on the implementation of best available technology for specific industrial processes. The industry must provide an action plan for how it will implement best available technology. Experiences show that this often results in a realistic action plan generating commitment from all stakeholders;
- compulsory notification of accidents;
- licensing of specified polluting processes;
- compulsory emission standards required under licence conditions: many developing countries have set emission standards for different types of industries. However, enforcement is often weak. An enforcement strategy should be addressed; and
- setting strict fines for exceeding emission standards.

Land use planning and zoning

The main techniques used are:

- use of planning regulations to restrict the location of new industries, for example to avoid proximity to residential zones or other sensitive land uses, and to establish suitably sited and serviced industrial areas;
- compulsory EIA for specified new major industries to require assessment of their potential for air pollution and to recommend improvement in location, processes, fuels, industry technology and emission limits. The most powerful and cost-effective AQM options occur during the planning stages for a new facility (WHO, 2000);
- relocation of existing industries away from residential and other sensitive land uses;

- control of visual appearance by planning guidelines and landscaping etc.

The last two measures do not reduce emissions and can, therefore, be only considered as secondary actions, particularly in view of of rapidly expanding urban areas.

Low Cost Options for Industrial Emissions

A number of low cost options exists which could achieve a reduction in industrial emissions with relatively low demand on financial, human and data resources. The cost of implementing each policy instrument will also be dependent on local circumstances and existing political, regulatory and administrative structures.

Ban the import of obsolete technologies from developed countries

A general low cost option for SSA countries is not to permit the import of obsolete technologies from developed countries. Technologies imported in developing countries should follow the same state-of-art technology as those in developed countries. Banning the import of obsolete technologies would avoid health and environmental impacts which will be much more costly to address once the technology is installed.

Set limits on the sulphur content of imported coal

Sulphur content of imported coal should be below 1 per cent. Low sulphur content in fuels reduces SO_2 and sulphate emissions. The sulphur content of coal does not influence the price on the world market.

Emissions of SO_2 are proportional to the sulphur content of the fuel, although with regard to coal a proportion, usually less than 10 per cent, is retained in the ash. Therefore, one of the simplest ways to reduce the amount of SO_2 released from the combustion process can be achieved by switching to a fuel that has a lower sulphur content (i.e. burning low sulphur coal or gas instead of high sulphur coal). The coal sulphur content can vary from below 0.5 per cent to over 10 per cent by weight. Burning low-sulphur coals seems to be the simplest and often the cheapest method to decrease national SO_2 emissions.

On the international coal market low sulphur coal is no more expensive than high sulphur coal as the price of coal depends only on the coal's heating value (Lorenz and Grudzinski, 2003).

Desulphurisation of flue gases

Flue gas desulphurisation in scrubbers is the most cost-effective methods to reduce SO_2 emissions in existing power plants and industrial boilers. The polluter pays principle would mean that the owner of the facility would have to cover the costs.

Flue gas desulphurisation is the current state-of-the-art technology used for removing SO_2 from the exhaust flue gases in power plants that burn coal or oil to produce steam for the steam turbines that drive their electricity generators. The capital, operating and maintenance costs per metric ton of SO_2 removed (in 2001 US dollars) range between US$ 150 and US$ 4,000 per ton of flue gas, depending on the type of scrubber. This can be a low cost option for power plants and other boilers in SSA that are equipped with some type of scrubber.

Use of two-stage combustion; flue gas recirculation and reducing combustion preheat temperature and low excess air to reduce NO_x emissions

The use of two-stage combustion is a cost-effective method to reduce NO_x emissions in existing gas- or oil-fired plants. This is essentially a change in operating procedures.

With regard to $NO_{x,}$ emissions, methods known to reduce NO_x emissions include: two-stage combustion; flue gas recirculation; and reducing combustion preheat temperature and low excess air. NO_x flue gas concentrations can be lowered by 20 to 30 per cent by reducing excess air rates. The effectiveness of low excess air combustion is proven for gas and oil combustion, but not for coal-fired equipment (Alpert et al., 1974).

The two stage combustion involves low excess air firing and afterburning with the remaining air. It constitutes one of the most effective NO_x control methods. Substantial reductions of 40-90 per cent of NO_x emissions may be achieved by this method in larger gas- or oil-fired plants.

A 20 per cent recirculation of cool flue gas and its injection through the burner can reduce NO_x emissions of furnaces by up to 60 per cent. A 100 per cent reduction in air preheat with natural gas firing can reduce NO_x flue gas concentrations by 20 per cent.

A combination of these techniques can further reduce NO_x emissions. These modifications refer to operation procedures and may be low cost options for SSA countries.

There are no low cost options for removal of PM in power plants and industries. Generally, mechanical collectors, wet scrubbers, fabric filters or bag houses and electrostatic precipitators are used to control PM from exhaust flue gases leaving coal and oil-fired generating units. In this case only the polluter pays principle can be applied. Figure 7.1 shows the comparative costs of the various methods. The least expensive methods are the mechanical collectors.

Coal-burning electric power plants are major sources of the CO_2. There is a need for simple, inexpensive new technologies to remove CO_2 from smokestack gas. A new CO_2-capture process called a Carbon Filter Process is a simple, low cost filter filled with a porous carbonaceous sorbent that works at low pressures. Modelling data and laboratory tests suggest that this device works better than existing technologies at a fraction of their cost (Radosz et al., 2008). This process has the potential of becoming a low cost option for SSA countries.

Increased energy efficiency in production to reduce overall energy demand leading to lower fuel consumption and lower emissions

Enhanced energy efficiency leads to better combustion and lower emissions of gaseous air pollutants.

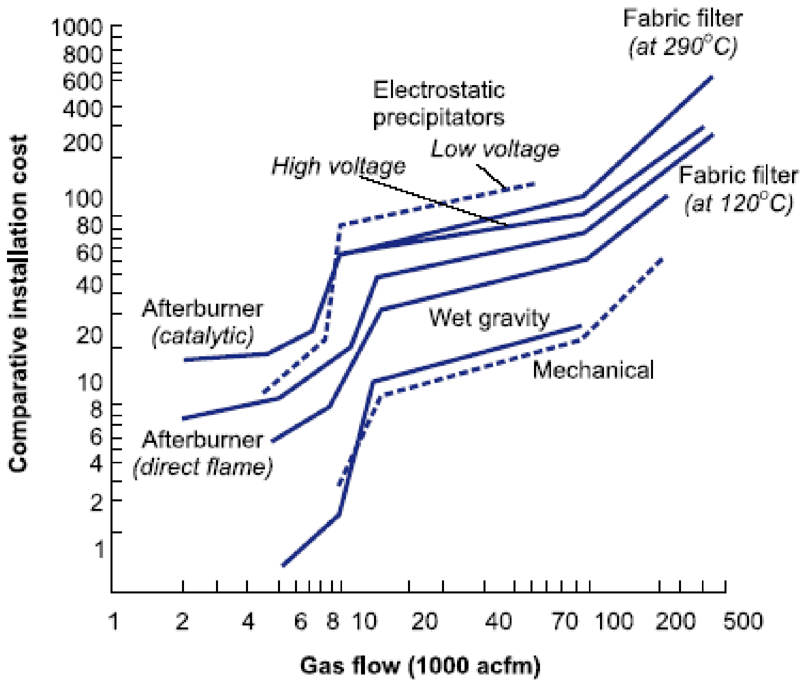


Figure 7.1: Comparative cost of PM control devices as a function of flue gas flow (in actual cubic feet per minute acfm = 472 L/s)

Source: anon

Transport Sector

Air pollution from the transport sector has important health and environmental effects. Road transport is responsible for a significant proportion of NO_2 and PM (PM_{10} and $PM_{2.5}$), which are the pollutants most likely to exceed air quality objectives. Therefore reducing emissions from road transport is a key part of local AQM.

A number of measures can be adopted which address not only vehicle pollution control but demand management. To achieve an environmentally sustainable transport system, ensuring a minimal environmental impact both in the short- and long-term, measures will need to be taken to reduce the overall demand for travel, and to encourage the use of less polluting modes of transport. This requires the adoption of a combination of measures ranging from emission standards to land use policies, in order to ensure that the overall need to travel and vehicle pollution are reduced (Gwilliam et al., 2004).

However, none of these strategies alone will provide the optimum solution. Combinations of strategies applied progressively over a period of time and in an integrated manner will normally achieve the best results, although the details and optimum mix of strategies will vary according to local circumstances. The strategies for managing pollutants from transportation activities are discussed below.

Land use

Land use planning has important implications for energy consumption and vehicle-related air pollution. Travel and transport developments interact to allow significant land use changes. The result has been the development of more energy-intensive land use and increased vehicle activity patterns. Land use planning has been shaped by the increasing dominance of the motor vehicle as the main mode of transport. As urban developments become more decentralised, and move to the fringe of the city, there is an increase in car dependence for normal everyday travelling, to work, school, shopping and leisure activities.

There is a need to integrate land use and transport planning within local AQM strategies in order to improve air quality and change travel behaviour. The provision of infrastructure in the past has shown that it exacerbates rather than solves the problem. New roads can generate more new traffic (SACTRA, 1999).

Traffic management

Traffic management can be used to reduce vehicle emissions. Traffic management measures have included computerised traffic light control, network and junction design, parking controls, reducing the supply of space allocated to car parks, speed limits, restricted access for non-essential traffic, bus priority lanes, pedestrian areas and cycling facilities. These measures not only reduce energy use but also provide an environment which is more people-friendly and which encourages greater walking and cycling.

Small traffic management schemes can influence air quality in their immediate vicinity, but are likely to have a relatively small effect over a larger area. Free-flowing traffic and smooth driving techniques usually mean lower emissions and better fuel consumption. It should be a general objective of traffic management to reduce congestion, making smoother driving possible, but without speeding. However, improving traffic flow and reducing congestion may attract more vehicles and additional measures may be required to prevent an increase in vehicle movements.

Enforcement of traffic laws and regulations can provide considerable improvement in traffic flow (USEPA, 1998). However, improved traffic flow can also generate increased traffic unless used in combination with management of traffic demand. This may include measures to discourage use of vehicles in congested areas of the city during peak periods by using parking policies, congestion charges, and electronic road pricing. Travel demand management is attractive to SSA cities as it normally involves implementation of relatively low cost actions with considerable success.

Encouraging alternatives to the private motor vehicle

Use of public transport and non-motorized transport (NMT) can help reduce transport emissions by reducing use of private vehicles. However, efficient bus or rail systems need to be developed by making them sufficiently attractive to induce high occupancy rates. High standards of quality of service need to be implemented to avoid or curtail the operations of informal transport providers using small, old, polluting, and poorly maintained vehicles. Bicycle and pedestrian programmes also need to be attractive to the public by giving emphasis to safe and efficient transport.

Reducing motor vehicle emissions

Improvements in fuel and vehicle technologies provide cost-effective options to reduce vehicle emissions in many developing countries where there is a rapid growth in private vehicle ownership. SSA countries may have large numbers of older vehicles with poor levels of maintenance and high emission factors. Governments can implement the use of cleaner fuels and tighter emission standards for new vehicles without direct additional costs to governments. They achieve this by passing the costs to consumers, and amending the taxation schedules to reduce taxes on cleaner fuels and vehicles and increasing the taxation on polluting fuels and vehicles. However, regulations to reduce fuel adulteration and substitution, which is prevalent in some SSA countries, should be considered. Fuels and vehicles can be thought of as a joint system, as cleaner vehicle technologies usually require improved fuels.

Cleaner fuels usually involve the elimination of lead, and reductions in sulphur, benzene, vapour pressure and total aromatics in petroleum, and lowering the density, sulphur, and polycyclic hydrocarbons in diesel. The introduction of cleaner fuels needs close consultation with stakeholders, particularly the oil and auto industries, and usually requires short- and medium-term strategies to enable the fuel and vehicle industries sufficient time to adapt. Countries importing fuel and vehicles find it easier to impose tighter emission and fuel standards than do manufacturing countries.

Improving fuel quality may also involve the introduction of alternative fuels to reduce particle emissions. These alternative fuels include LPG, CNG, biofuels, hydrogen and electricity. In addition to reducing emissions of air pollution, these fuels may diversify energy sources and reduce GHG emissions. Vehicle technologies being used to reduce emissions include catalytic converters, exhaust gas recirculation, and diesel particle traps. Use of these technologies in new vehicles is largely driven by new vehicle emission standards.

Without a balance between the emission standards for new vehicles and for in-use vehicles, there can be adverse unintended consequences. Stringent requirements for new vehicles can be expensive, and if standards for in-use vehicles are lax or not effectively implemented, vehicle replacement is delayed, resulting in an ageing, high emission vehicle fleet. Effective implementation of standards for in-use vehicles is necessary to ensure that vehicles with high levels of emissions are repaired or retired from the road.

Vehicle inspection and maintenance (I&M) programmes can successfully reduce emissions from old vehicles and ensure that new vehicles remain in good condition. Emissions of CO and HC can be reduced up to 25 per cent through strict I&M programmes. Criteria pollutants commonly regulated for in-use diesel vehicles are PM, smoke, and NO_2 for petrol-fuelled vehicles, CO, HCs, and NO_x and for two- and three-wheeled vehicles, CO, HCs and smoke (ADB, 2003). These I&M programmes also accelerate the disposal of old and inefficient cars. However, they may face financial, political and enforcement difficulties. Different countries have had varying levels of success with effective implementation of I&M.

Test procedures should be designed to make it difficult to cheat or avoid testing, and to minimise differences between test centres and maximize reproducibility. Strong independent oversight and auditing of the system is required.

If resources are limited, it is usually advisable in the initial phase of implementation to focus resources on a limited number of vehicle categories, such as vehicles that travel a large number of kilometres per year and are heavily polluting (such as commercial diesel vehicles) in preference to testing every vehicle every year (Gwilliam et al*.*, 2004).

Where centres conduct both testing and maintenance it is difficult to supervise and audit the test and repair systems to provide quality control and prevent corruption. Outcomes are better where the testing and repair functions are clearly separated with centralised, test-only I&M centres (ADB, 2003).

Low Cost Options for Transport Emissions

A general low cost option to reduce motor vehicle pollution is better traffic management which reduces congestion and makes smoother driving possible. Measures include banning or restricting traffic, parking restrictions, promoting bus public transport, walking and cycling. As well as the direct pricing of road use and integrating land use and transport planning with local air quality management strategies to improve air quality. Poor traffic management, congestion, exposure to traffic pollution and fear of accidents are a disincentive to people to both walk and cycle in an urban environment. Measures should therefore be taken to improve the attractiveness of public transport, walking and cycling. Relatively low cost options that could be used to reduce motor vehicle emissions include the following.

Traffic management

Smoothing traffic flow and reducing speed, banning or restricting traffic, or particular types of vehicles, working with business and public to raise awareness of implications of transport choice.

Stop-and-start driving, typical of congested traffic, increases total emissions of PM for the same distance travelled. Traffic management can smooth out speeds on existing traffic volumes and reduce emissions. CO, hydrocarbons, and PM emission levels tend to fall and NO_x emissions rise, with increasing vehicle speed.

Regulation and control of public bus transport

The promotion of bus public transport can reduce the use of motor vehicles in the city centre. The cost and quality of public transport are important factors that may influence its use. The maintenance of the bus fleet is important so they add to existing air quality problems.

Large buses with high occupancy can displace a number of small vehicles potentially reducing both congestion and aggregate emissions. However, if buses are grossly polluting, and especially if they are under occupied, then the impact of emissions or congestion or both could be negative. Regulation and control of public bus transport can help make it clean, efficient, attractive, and affordable.

Segregated lanes

Use of segregated lanes on key road corridors for bus public transport, high occupancy vehicles or cycling allows a more efficient use of the road system and can encourage use of bus public transport or high vehicle occupancy or cycling. For example, segregated bus way systems can often yield substantial environmental benefits at much reduced cost.

Non-motorized transport

The provision of safe and comfortable facilities for walking, cycling and other forms of NMT increases the use of NMT and can reduce the number of short motorized trips, which are disproportionately polluting. Segregation of motorized and NMT is important for environmental, safety, and efficiency reasons.

Physical restraint

Restricting vehicle use in certain areas such as urban centres can take the form of limiting use of vehicles on specific days or in specific areas. However, people must be able to reach the area by other means. An effective policy, with a concomitant reduction in pollution, is likely to combine car restraint and public transport improvement.

Parking policies

Policies which combine limitations on the number of parking spaces together with high charges for long-term parking have been successfully used in European countries, particularly to discourage commuting trips by cars. A strong regulation to limit on-street parking to locations where it has no effect on traffic flow is likely to reduce both congestion and the demand for motorized transport. Parking restrictions need the right level of enforcement. Effective enforcement of parking restrictions allows more efficient use of existing parking provision and improves parking flows as drivers have to spend less time finding a parking space.

Road pricing

Direct pricing of road use has a high potential for generating local revenue and reducing congestion and air pollution. Underpricing the use of transport infrastructure will tend to increase the number and lengths of motor vehicle trips. Options to introduce road pricing include direct pricing of road use such as tolls and congestion pricing. The level of sophistication can vary from electronic systems to attendants in kiosks at particular toll roads to take payments

Land use

Integrating land use and transport planning with local air quality management strategies can improve air quality. Population density and city structure affect the demand for transport. A low density population with a high dispersion of residential areas and places of employment would not only increase demand for transport but also make provision of accessible transport services uneconomic. A policy which increases or maintains population density favours the concentration of employment and retail activity in a central area and can reduce local motor vehicle pollution.

Ban the import of obsolete vehicles and phase-out old vehicles still circulation

Many vehicle fleets in SSA cities are older than 14 years. Obsolete vehicles which would not be licensed anymore in their countries of origin emit 10 times more air pollutants than newer vehicles. A low cost option is to not allow the import of obsolete vehicles and to phase-out old vehicles already in circulation.

Use of low sulphur fuels in vehicles

The use of low sulphur fuels in vehicles, particularly diesel-driven vehicles reduces the emission of ultra fine sulphates which are a serious threat to human health because they can be carcinogenic.

Area Sources

Forest fires, burning of biomass and open burning of waste can be major contributors to poor air quality in a city. Air pollution due to natural processes, including PM transported from bare soil may also contribute to poor air quality. Surface mining and overgrazing of land in semi-arid areas can act as sources of particles. Prevention and control strategies may include enforcement of bans on burning of materials or waste, and promotion of alternatives to burning. These may also include paving roads, establishing re-vegetation programmes in dust control areas and use of street sweeping equipment. Education strategies may involve informing the community about sources of emissions, and the impact of these practices on health and the environment (WHO, 2000).

Open burning of waste can produce toxic emissions. To address this issue it is necessary to identify areas where this occurs, assess the extent of the problem; then assess the adequacy of the city's provision of disposal means in these areas and, if necessary, improve the facilities and capacities for solid waste management (SWM). The present SWM situation in SSA countries can be characterised as sub-standard, inefficient and hampered by serious organisational and technical lacks, resulting in various dysfunctional systems and many related negative effects on the environment and public health (see Table 7.4). Household, industrial and medical waste are sometimes deposited in the same landfill sites. Used car accumulators generated in SSA countries are not collected and usually end up at illegal dumps or are mixed with the municipal solid waste (MSW) and disposed at municipal landfills. No incineration facilities for the disposal of SWM exist in SSA countries.

Table 7.4: Challenges of waste management in SSA countries

Area	Challenges
Policy and legislative	• Incomplete legislation • Lack of monitoring and enforcement
Institutional and organisational	• Unclear roles and responsibilities of stakeholders • No waste department at the Ministries of Environment • Lack of private sector participation • No arrangements for financial/economic instruments in place
Technical/operational	• Insufficient coverage of organized waste collection • Low standards for MSW collection and disposal • No separate collection and treatment of hazardous wastes • Insufficient separation of medical wastes and standards for treatment • No separate collection of special waste streams • Lack of market for recyclables, low environmental standards
Economic/financial issues	• Low municipal cost recovery rate • Lack of funds for logistical and disposal infrastructures • Lack of instruments to stimulate changes
Human resources/Capacity enhancement	• Weak capacities at stakeholders • Weak monitoring/enforcement capacities at all levels • Lack of self-monitoring capacities
Stakeholder and Public Awareness	• Lack of communication at all stakeholder levels • Lack of communication strategy with the general public

SWM strategic objectives and targets include:

- SWM policy and legislative framework development;

- Institutional/organisational arrangements;
- Human resources and capacity enhancement;
- Final disposal facilities;
- Waste separation, storage, collection and transport systems;
- Financing and cost recovery instruments;
- Stakeholder awareness and communication;
- Data availability and reporting requirements;
- Waste avoidance and reduction targets;
- Waste recovery and recycling systems;
- Waste treatment and processing facilities.

The industrial hazardous waste handling in the main industry sectors (mining, smelters, cement factories, and process industries) and power plants shows a clear lack of any standard or compliant management of the generated hazardous wastes. No proper separation, classification and packaging/labelling or storage is undertaken by industry and consequently the hazardous waste is disposed of without any environmental precautions, thus creating continuous industrial 'hotspots'. Hazardous medical waste in SSA countries is not handled or treated in a compliant way and is mostly disposed of at municipal dump sites.

Recycling is presently not financially feasible in SSA countries since the net costs are considerably higher than the costs of land filling. This is mainly due to the high costs of the required separate collection, limited volumes and lack of proper processing facilities. In order to stimulate and increase the recycling rates, the introduction of specific product charges and taxes would be necessary. The required extensive organisational capabilities at national and local level however are not considered adequate yet to handle such complicated systems. Therefore the introduction of "producers' responsibility" is strongly recommended as a low cost option; an approach that is increasingly applied in other countries.

Low Cost Options for Area Source Emissions

Ban deliberate open burning in urban areas and at municipal waste deposits

A ban of open burning in urban areas helps reduce pollutant emissions. A collection, expert disposal and/or treatment must exist in order to enforce the ban.

Facilities for waste treatment such as waste incineration plants are expensive. A low cost option for air pollution caused by area sources would be to ban deliberate open burning in urban areas and at municipal waste deposits. However, two challenges occur as a consequence of such a ban:

1. If open burning of wastes in urban areas are banned and the ban enforced, a viable collection, disposal and/or treatment system of SWM must be available.
2. Due to the high ambient temperatures experienced in most SSA countries accidental burning of waste deposits also occurs, in particular if municipal and industrial wastes are deposited together.

Burn municipal and industrial hazardous wastes in existing cement plants at high temperatures

Hazardous wastes must be treated before deposition of their residues. Municipal waste incinerators are expensive due to the high temperatures of incineration needed. Cement plants use incinerating temperatures high enough to burn most hazardous wastes and produce non-hazardous ashes and residues. Provided that transport facilities for wastes exist, a low cost option to treat municipal and industrial hazardous wastes would be burning the wastes in existing cement plants at the high temperatures that are used there.

Collection and use of used tyres as fuel in tar and lime production facilities if they exist or processed in cement kilns

Open burning of used tyres in urban areas and on waste deposits leads to high emissions of PM and should therefore be avoided. Their incineration in tar and lime production facilities or cement kiln avoids this problem.

In SSA countries most used tyres from motor vehicles are currently sent to landfill. Apart from locally generated quantities, there is the import of used tyres for rethreading. Energy recovery is not currently applied. Used tyres could be collected and used as fuel in tar and lime production facilities if they exist or processed in cement kilns.

Low Cost Options for All Emission Sources

Using WHO air quality guidelines to set air quality standards

WHO has derived air quality guideline (AQG) values and exposure times for approximately 50 non-carcinogenic compounds and unit risk (UR) values for approximately 30 carcinogenic pollutants (WHO, 2000). A few of these AQG values – for SO_2, O_3 and PM - have been recently updated (WHO, 2005). The AQG values of WHO are derived in expert consultations in which the globally available literature on air pollution induced adverse health impacts is compiled, reviewed, evaluated and AQG and UR values developed on the basis of the exposure-response relationships reported in the literature. Non-carcinogenic AQG values reflect a low risk of incidence of adverse health effects if the AQG values are complied with. If the AQG values are exceeded this does not necessarily mean that adverse effects occur in a population but only that the risk for such effects increases. The AQG can be utilised for setting national air quality standards. Experience from developed countries may be used to collect information on the acceptable number of times standards are exceeded. A participatory approach in setting standards which involves stakeholders (e.g. industry, local authorities, NGOs, media and the general public) assures - as far as possible - social equity or fairness to the parties involved. The provision of sufficient information and transparency in standard setting procedures ensures that stakeholders understand the environmental, health and socio-economic impacts of such standards.

Setting air quality standards on the basis of WHO AQG values does not mean that the adopted standards have to have the same WHO values. Rather air quality standards have to be set considering the prevailing exposure levels and the environmental, socio-cultural and economic conditions in a country. WHO's AQG values, therefore, should be considered as target values, only to be implemented stepwise. Presently, in most countries air quality standards are above the WHO AQG values. For PM the WHO has developed a procedure of setting intermediate air quality standard values which can be implemented in the medium- to long-term (WHO, 2005).

Use of the WHO AQG values to set air quality standards is a low cost option for developing countries in SSA.

Use of a simple integrated model for air quality management

The **Simple Integrated Model for Better Air Quality (SIM-AIR)** is a relatively new interactive model to examine emissions, ambient air quality, and health. While it relies on some of the basic approaches and emission factors contained in AP-42, CORINAIR, and RIAS, it is based on an integrated AQM approach and provides a user-friendly visualisation of rapid assessment of pollution data and control options. The SIM-AIR integrated approach has a number of advantages:

- allows definition of all major types of urban emission sources, such as point, mobile, and area;
- provides default emission factors where available (users can change these factors based on local context, or use CORINAIR, AP-42 or RIAS emission factors);
- interfaces an emission computation model with key technology and management options (e.g. fuel change, conversion of two stroke to four stroke engines etc.);
- links emissions to ambient air quality through an externally created or supplied
- source-receptor matrix (this allows user to apply an urban air quality model of their choice. SIM-AIR is thus independent of the air quality model);
- allows estimation of economic impacts on health. The user can edit exposure-damage relationships according to local knowledge;
- allows input of cost data for a broad range of AQM options;
- encourages rapid assessment of management options in terms of cost effectiveness;
- provides an optimisation scheme to identify most cost-effective option combinations.

SIM-AIR uses a “main” worksheet and eight other “theme” worksheets to display the output in Excel format. The eight themes include emission distribution of non-transport sources, vehicle data, emissions inventory, a menu of options, health impacts, transfer coefficients to compute ambient concentrations, ambient concentrations, and, finally, a help worksheet. The result is that for any grid of the study area, the input data contains information on emission distribution, ambient concentration, health impacts, and management options.

The SIM-AIR model is primarily a training tool and should not be used as the only support system for decision making. However, as a training tool, it helps to understand how different management options can influence health impacts.

Transboundary Air Pollution

The transboundary movement of air pollution across borders may cause adverse effects in countries other than the country of origin. With advanced monitoring and modeling technology there is more evidence that pollution emitted in one part of the world can create adverse effects in other parts. Pollutants with a potential for regional and intercontinental transport include: fine particles; acidifying substances (SO_2,

NO_x); O_3 and its precursors (VOC and NO_x); heavy metals (mercury); and persistent organic pollutants (POPs).

Pollutant levels at a location are determined by a combination of processes, including the intensity of local source emissions, the atmospheric capacity to dilute the emission, the natural removal processes, the physical and chemical transformation of pollutants, and the amount transported from upwind regions. Dust from the Sahara regularly causes a number of high PM events in Europe and even reaches Central and South America, and occasionally the State of Florida. Emissions from human activities in populated cities may be transported over large distances.

Within SSA, the major transboundary air pollution issues of concern include: regional haze from forest fires, atmospheric brown cloud (ABC), acid deposition and regional dust. In addition, trace elements from coal combustion, particularly mercury (Hg), have a high potential for long-range transport (UNEP, 2003, Pottinger et al., 2004).

Regional Haze from Forest Fires

Haze is the suspension of extremely small (dry) particles in the atmosphere which are invisible to the naked eye. However, they are numerous enough to give the atmosphere an appearance of opalescence together with reduced visibility (ISO, 1994). Sub-micron particles effectively scatter and absorb sunlight and affect cloud formation, which may introduce a range of effects from visibility reduction to climate change.

Smog is fog which has a high content of air pollutants (WMO, 1992). Smoke is an aerosol originating from combustion, thermal decomposition or thermal evaporation. Its particles may be solid (magnesium oxide smoke) or liquid (tobacco smoke) (IUPAC, 1997). The International Standard definition of smoke is that of a visible aerosol usually resulting from combustion (ISO, 1994) or as a suspension in the atmosphere of small particles produced by combustion (WMO, 1992).

Biomass-burning emissions observed in the dry season campaign of SAFARI 2000 led to “massive thick aerosol layers covering much of Southern Africa” (Schmidt et al., 2003) and pronounced smoke and haze that traversed Southern Africa during September 2000 (Annegarn et al., 2002) and exited the subcontinent as a “river of smoke” towards the Indian ocean (Swap et al., 2003; Ramanathan et al., 2007).

Atmospheric Brown Cloud

An atmospheric phenomenon, labelled now Atmospheric Brown Cloud (ABC) has generated concern among scientific community and policy makers (Ramanathan and Crutzen, 2003). The scientific study of the phenomenon which occurs over all continents and extends to the Atlantic and Indian oceans has estimated the brownish cloud to be a 3 km thick blanket of pollution, which is composed of black carbon, organic carbon, sulphates, nitrates, mineral dust and fly ash. Anthropogenic sources are estimated to contribute to this haze.

The ABC is transported far from the source regions. Hence it is not only a threat for the SSA countries where it originates but to the entire African sub-continent and beyond. It is not known if the haze is responsible for causing respiratory diseases and other ailments. Aside from potential health impacts, the haze also reduces the sunlight reaching the earth surface, possibly altering the region’s climate, cooling the ground while heating the atmosphere. A reduction in photosynthesis resulting in a reduction in agricultural productivity is another potential effect.

Acid Rain in Sub-Saharan Africa

Acid rain is now emerging as a major problem in SSA with potentially widespread and severe impacts. Acid deposition includes both dry and wet deposition. The term ‘acid rain’ is normally used to address the wet acid deposition though it is sometimes used interchangeably with ‘acid deposition’. Rain water is naturally slightly acidic due to the presence of CO_2 in the air. The “pure” rain’s acidity is pH5.6-5.7. A wide-range of pollutants in the atmosphere such as SO_2, NO_x, ammonia, organic compounds, and wind blown dust, can lower pH of rain water. Acid rain refers to all types of precipitation that has pH below 5.6. Major man-made precursors of acid rain are SO_2 and NO_x.

Acid deposition is a serious environmental threat. The resulting effects depend on the amount of acid compounds deposited to particular receptor surfaces and on the sensitivity of these surfaces to acid deposition. In general, acid rain can kill aquatic life, can damage trees, crops and other vegetation, buildings and monuments, can corrode metals, can reduce soil fertility and can cause toxic metals to leach into underground drinking water resources. In addition, SO_2 and NO_x and fine sulphate and nitrate particles may cause visibility reduction and adverse health effects.

In SSA energy consumption and the use of sulphur-rich coal as a cheap fuel and oil are rapidly increasing. An assessment of the present and possible future acidification and eutrophication of natural and semi-natural terrestrial ecosystems showed that risks were found for parts of Western, Eastern and Southern Africa. Scenario analysis shows that both acidification and eutrophication risks could be significantly increase in these regions (UNEP, 1999).

Control strategies available to mitigate significant acid deposition and its ecological consequences address reductions in both SO_2 and NO_x emissions, and mitigate effects on sensitive receptors. Use of low-sulphur fossil fuels (low sulphur coal and oil, and natural gas) and low NO_x burners can help to reduce SO_2 and NO_x generation during combustion. Flue gas desulphurisation and denitrification are post-combustion methods to remove the pollutants from flue gas. For vehicle emission reduction, low sulphur fuels and NO_x control devices can be applied. Increased energy efficiency in production and in society as a whole will help to reduce overall energy demand leading to lower fuel consumption and lower emissions.

Emission control technologies may take many years to reduce SO_2 and NO_x emissions in order to solve the challenge of acid deposition. Short-term measures, such as liming of acidified surface water bodies, are necessary to save or restore many important resources. Many alkaline materials, such as lime compounds, and soda ash, can be used for this purpose. However, the effects of acid deposition are long-lasting. If soil is chemically changed it may take many decades for all the linked ecosystems to recover.

Sub-Saharan Sandstorms and Desertification

Sand storms or dust storms occur in SSA particularly in the early months of the year. A dust storm occurs when strong winds sweep up large quantities of dust particles and suspend them in the air. Large particles (>10 μm) will settle near the source within the first day of transport and cause their greatest impact on the local and neighbouring regions. Finer dust particles may be lifted up as high as 1-3 km into the atmosphere. They can be resident in the atmosphere for a period of 5-10 days during which they are transported over large distances. The resulting dust clouds often obscure the sun, and reduce visibility. As a consequence, traffic is slowed down, more accidents occur, and airports are closed. Dust storms have been reported to cause episodic PM concentrations within and beyond SSA.

Dust storms have occurred frequently during the last 50 years and especially during the last few years. This is believed to be a result of the severe extension of the Sahel zone as well as drought and uneven/reduced rainfall caused by global climate change. Dust storm carry bacteria, microbes and fungi; also mercury, pesticides and other chemicals, such as byproducts of burned plastic garbage may be present in the dust (USGS, 2003). Dust storms have been associated with outbreaks of meningococcal disease in SSA (Robinson and Lester, 2002). For this reason, the World Meteorological Organization (WMO) is developing a dust storm warning system for Europe, Africa and Middle East (WMO, 2007). The United Nations (UN) has issued a desertification warning saying over the next decade tens of millions of people could be driven out of areas impacted by sandstorms (UNU, 2007). As defined by the UN Convention, desertification is a process of "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities".

The biggest factor leading to intense dust storms in recent years is inappropriate development such as overgrazing. Only by decreasing the damage caused by human activity and restoring the natural environment will it be possible to fundamentally mitigate the problem. There is no low cost solution available.

Tropospheric Ozone Pollution

Tropospheric ozone pollution is a transboundary in nature. Available data shows that ambient concentrations of O_3 are causing both visible injury and economic damage to crops, forests and natural ecosystems (Heck et al., 1998; Emberson et al., 2003). It is also clear that injurious effects of O_3 on vegetation frequently occur as a result of cumulative exposures over many days, weeks and months rather than during a few hours of peak ozone days (Heck et al., 1999). O_3 concentrations in the SADC region are currently comparable to levels that caused crop yield reductions in Europe (Zunckel et al., 2003; van Tienhoven et al., 2006). O_3 actually kills plants by inhibiting their ability to open the microscopic pores (stomata) on their leaves and breathe (Roach, 1999).

Ozone pollution originating in urban areas can extend into surrounding rural and forested areas that are hundreds of kilometres downwind. Episodes of elevated ozone concentrations are associated with warm, slow moving high pressure systems and have concentrations between 60 and 100 $\mu g/m^3$. O_3 is a powerful photochemical oxidant that damages rubber, plastic, and all plant and animal life. O_3 impacts on human health include a number of morbidity and mortality risks associated with lung inflammation. Other respiratory ailments including asthma, emphysema, and bronchitis represent the primary health problems associated with human exposure to ground level ozone (WHO, 2000). Children are especially susceptible to O_3 related illnesses because on average they spend more time outdoors than adults and their airways are narrower than adults. It also reacts with hydrocarbons from automobile exhaust and evaporated gasoline to form secondary organic pollutants such as peroxyacyl nitrates that are very irritating to the eyes and throat (WHO, 2000; 2005).

The only solution to reduce O_3 concentrations is to reduce its precursor air pollutants NO, NO_2 and hydrocarbons.

Import of Hazardous Chemical Waste

The importation of hazardous chemical waste in SSA countries is another form of transboundary pollution. Three conventions regulate the importation of hazardous chemicals and hazardous wastes: the Rotterdam Convention, the Basel Convention and the Bamako Convention (see Table 7.5). The Basel Convention was designed to prevent transfer of hazardous waste from developed to less developed countries (LDCs) and was amended by Decision III/1 which bans the importation of certain hazardous wastes from developed countries to LDCs. The Bamako Convention is a treaty of African nations prohibiting the import of any hazardous (including radioactive) waste. The Stockholm Convention outlaws certain POPs and curtails the inadvertent production of dioxins and furans.

Most SSA countries are parties of the Basel, Rotterdam and Stockholm Conventions but fewer countries have ratified the more stringent Amendment III/1 to the Basel Convention and the Bamako Convention.

Disposing of hazardous chemicals and hazardous wastes in landfills may lead to dangerous pollution of air, soil and water and public health hazards if poor people are searching the landfill for usable objects. Landfills in SSA countries are often smouldering or even burning and emissions of VOCs and heavy metals may be substantial.

Rarely, if at all, do cities in SSA countries have regulations limiting or preventing hazardous wastes from being dumped at a landfill. If they do, the regulations are either not enforced or unenforceable because the hazardous waste can be readily mixed with ordinary refuse and thus go undetected.

A common method of treatment of hazardous waste is combustion or incineration. which is used to destroy hazardous organic constituents and reduce the volume of waste. Depending upon the type of waste and its constituents, residual ash may in some cases be landfilled or may require further treatment. Hazardous waste must be treated before it can be disposed. However, facilities for the treatment of hazardous chemicals and hazardous wastes are lacking in SSA countries. In order to avoid additional challenges of air pollution due to importation of untreated hazardous chemical residues and wastes, a low cost solution for SSA countries is to ban the importation of hazardous chemicals and hazardous wastes (i.e. implementing Amendment Decision III/1 and the Bamako Convention).

Low Cost Options for Transboundary Pollution

Use of low-sulphur fossil fuels (low sulphur coal and oil, and natural gas)

Combustion of low sulphur fuels in industries and motor vehicles reduces the emission of ultra fine sulphates which are a serious threat to human health.

Use of low excess air NO_x burners in industries can help to reduce NO_x emissions during combustion

This is a cost-effective method to reduce NO_x emissions in existing gas- or oil-fired plants and is essentially a change in operating procedures. The polluter pays principle should always apply but in the case of transboundary pollution this needs to be agreed among a number of countries.

Table 7.5: Parties to the Stockholm, Rotterdam, Basel and Bamako Conventions

Country	Stockholm Convention (POPs) 2001	Rotterdam Convention (Hazardous Chemicals) 1998	Basel Convention Amendment Decision III/1 1995	Bamako convention (Hazardous Wastes) 1991	Basel Convention (Hazardous Wastes) 1989
Angola	X	X			
Benin	X	X		X	X
Botswana	X		X		X
Burkina Faso	X	X		X	X
Burundi		X		X	X
Cameroon	X	X		X	X
Cape Verde	X	X			X
Central African Republic					X
Chad	X	X			X
Comoros	X	X		X	X
Congo-Brazzaville	X	X		X	X
Congo-Kinshasa	X	X		X	
Côte d'Ivoire	X	X		X	X
Djibouti	X	X			X
Equatorial Guinea		X			X
Eritrea	X	X			X
Ethiopia	X	X	X	X	X
Gabon	X	X			
Gambia, The	X	X	X	X	X
Ghana	X	X	X		X
Guinea	X	X		X	X
Guinea-Bissau	X	X			
Kenya	X	X			X
Lesotho	X	X			X
Liberia	X	X	X		X
Madagascar	X	X			X
Malawi	X				X
Mali	X			X	X
Mauritania	X	X			X
Mauritius	X	X	X	X	X
Mozambique	X			X	X
Namibia	X	X		X	X
Niger	X	X		X	X
Nigeria	X	X	X		X
Rwanda	X	X			X
São Tomé e Principe	X				
Senegal	X	X		X	X
Seychelles	X	X			X
Sierra Leone	X				
Somalia	X				
South Africa	X	X			X
Sudan	X	X		X	X
Swaziland	X				X
Togo	X	X		X	X
Uganda	X			X	X
United Republic of Tanzania	X	X	X	X	X
Zambia	X				X
Zimbabwe	X			X	

Source: BAN (2008); CIA (2008); UN (2008); UNEP (2008)

Use of flue gas desulphurisation and denitrification to remove the pollutants from flue gas

New plants to be installed in SSA countries should employ state-of-the-art technology as in developed countries with respect to desulphurisation and denitrification in order to avoid cost-intensive *a posteriori* measures or be forced to accept human health and environmental impacts.

Ban the importation of hazardous chemicals and hazardous wastes by implementing Amendment Decision III/1 to the Basel Convention and the Bamako Convention

A ban on the importation of hazardous chemicals and hazardous wastes from developed countries to SSA countries avoids the 'social dumping' of hazardous materials which cannot be properly treated in developing countries. Thus, all SSA countries should adopt Amendment Decision III/1 to the Basel convention and the Bamako convention.

For vehicle emission reduction, low sulphur fuels and NO_x control devices can be applied

The use of low sulphur fuels in vehicles, particularly diesel-driven vehicles reduces the emission of ultra fine sulphates. NO_x control devices (catalysts) reduce NO_x emissions and limits O_3 chemical conversion. A prerequisite for effective NO_x control is the supply of fuels of appropriate quality and existence of an enforced I&M system.

Global Air Pollution

The majority of SSA countries are parties to the international conventions relating to Biodiversity, Climate Change, Kyoto Protocol, Desertification, and Ozone Layer Protection, but only half of them are parties to the International Convention for the Prevention of Pollution from Ships (see Table 7.6). Even less SSA countries will have adopted Marpol Annex VI of the ship pollution convention which sets limits on NO_x and SO_x emissions from ship exhausts, and prohibits deliberate emissions of O_3 depleting substances. Two sets of emission and fuel quality requirements are defined by Annex VI: (1) global requirements, and (2) more stringent requirements applicable to ships in Emission Control Areas (ECA). In order to reduce impacts from ship pollution in pollution-sensitive ports of non-landlocked SSA countries a low cost solution for these countries would be to adopt the Convention including the voluntary Annex VI and propose the designation of a port as an ECA.

Climate Change

Measures to control air emissions as part of an AQM strategy tend to be immediate, more certain and occur at the place where the control measure is taken (e.g. urban or regional scale). In contrast, the impact of control measures on climate change is long-term and global. These differences have been reflected in the current scientific and policy frameworks, which tend to address these problems separately (IPCC, 2007). Policies to address urban air quality have tended be in the form of local and regional measures. However, these can be adapted at low cost to also reduce GHG emissions. This is particularly important for developing SSA countries, where air pollution reduction and climate change mitigation are only beginning to have a similar priority as economic and social development (NEPAD, 2003; UNEP, 2003; 2006). The Integration of air pollution abatement and climate change mitigation policies offers great potential to reduce polluting air emissions. Table 7.7 presents measures which are likely to lead both to reductions in emissions of both air pollutants and

GHGs. Such measures could form part of an integrated strategy to address both urban air quality and global climate change.

Clean Development Mechanism

The United Nations Framework Convention on Climate Change (UNFCCC) was signed in 1992 at the UN Earth Summit, and has been ratified by 192 countries. The ultimate objective of the Convention is to stabilise GHG concentrations in the atmosphere at a level that will prevent dangerous human interference with the climate system. Recognising that binding obligations are necessary to achieve the objective, countries adopted the Kyoto Protocol in 1997. The Protocol acknowledges that the industrialised countries must lead efforts to address climate change, and commits those included in Annex B to the Protocol to emissions targets. Under this Protocol, 36 industrialised countries and the EU have committed to reducing their emissions by an average of eight per cent by 2012 against 1990 levels. Industrialised countries must first and foremost take domestic action against climate change. However, the Protocol also allows them to meet their emission reduction commitments abroad through market-based mechanisms.

The clean development mechanism (CDM) is one of the Protocol's market-based mechanisms which permit industrialised countries to earn emission credits through investment in sustainable development projects that reduce emissions in developing countries. The CDM is a means for developed countries to achieve part of their target under the Kyoto Protocol by purchasing Certified Emission Reductions (CERs) from GHG reduction projects in developing countries. A prerequisite for a CDM project is that it must contribute to sustainable development in the host country. It is up to each host country government to decide and define their criteria for sustainable development. A UNFCCC body called the CDM Executive Board (EB) decides on the validity of the methodology for generating CERs of each project. Since the beginning of 2006, the estimated potential of emission reductions to be delivered by the CDM is more than 2.2 billion tonnes of CO_2 equivalent. This is approximately the combined emissions of Australia, Germany and the United Kingdom (UNFCC, 2007).

However, the current CDM project portfolio provides a limited contribution to tackling urban air pollution (Curb-Air, 2007). For example, the large number of renewable energy and efficiency projects approved under the CDM only have a significant impact to the extent they displace coal utilisation in or near urban areas. The same argument is valid for fuel switch projects. A sector analysis of air pollution reduction options based on their co-benefits (i.e. ability to reduce GHG emissions and improve urban air quality) shows that a number of options are available at the urban level (see Table 7.8) (Curb-Air, 2007).

Table 7.6: SSA Countries parties to international environmental conventions

Country	Biodiversity	Climate Convention	Kyoto Protocol	Desertification	Ozone Layer Protection	Ship Pollution
Angola	X	X	X	X	X	X
Benin	X	X	X	X	X	X
Botswana	X	X	X	X	X	
Burkina Faso	X	X	X	X	X	
Burundi	X	X	X	X	X	
Cameroon	X	X	X	X	X	
Cape Verde	X	X	X	X	X	X
Chad	X	X		X	X	
Cote d'Ivoire (Ivory Coast)	X	X	X	X	X	X
Central African Republic	X	X	X	X	X	
Comoros	X	X	X	X	X	X
Congo-Brazzaville	X	X		X	X	X
Congo-Kinshasa	X	X	X	X	X	
Djibouti	X	X	X	X	X	X
Ethiopia	X	X	X	X	X	
Equatorial Guinea	X	X	X	X	X	X
Eritrea	X	X	X	X	X	
Gabon	X	X	X	X	X	X
Gambia, The	X	X	X	X	X	X
Ghana	X	X	X	X	X	X
Guinea	X	X	X	X	X	X
Guinea-Bissau	X	X	X	X	X	
Kenya	X	X	X	X	X	X

Source: CIA (2008)

Table 7.6: SSA Countries parties to international environmental conventions (cont/)

Country	Biodiversity	Climate Convention	Kyoto Protocol	Desertification	Ozone Layer Protection	Ship Pollution
Lesotho	X	X	X	X	X	
Mauritania	X	X	X	X	X	X
Mauritius	X	X	X	X	X	X
Mozambique	X	X	X	X	X	X
Namibia	X	X	X	X	X	
Nigeria	X	X	X	X	X	X
Niger	X	X	X	X	X	
Rwanda	X	X	X	X	X	
São Tomé e Principe	X	X		X	X	X
Senegal	X	X	X	X	X	X
Seychelles	X	X	X	X	X	X
Sierra Leone	X	X	X	X	X	X
Somalia	X	X			X	
South Africa	X	X	X	X	X	X
Sudan	X	X	X	X	X	
Swaziland	X	X		X	X	
Tanzania	X	X	X	X	X	
Togo	X	X	X	X	X	X
Uganda	X	X	X	X	X	
Zambia	X	X	X	X	X	
Zimbabwe	X	X		X	X	

Source: CIA (2008)

Table 7.7: Examples of measures to reduce emissions of air pollutants and climate active pollutants and their effects

Measure	Effect
Switching from coal to natural gas for power generation.	Reduces CO_2 emissions for each kiloWatt generated. Emissions of SO_2 and NO_x are also reduced.
Efficiency improvements in domestic appliances and industrial processes, e.g. through technical developments.	Reduces emissions of both types of pollutant, but efficiency measures sometimes result in increased demand, which must be avoided.
Energy conservation, e.g. through improved insulation of houses.	Reduces emissions of both types of pollutant.
Use of new technologies in road transport, for example: • hybrid vehicles • hydrogen from natural gas or from renewable energy sources • lean burn petrol vehicles fitted with NO_x traps.	Reduces carbon dioxide emissions for each kilometer travelled and also emissions of NO_x and particulate matter. It is essential that the whole fuel/ vehicle cycle is analysed (e.g. the emissions associated with hydrogen generation).
Demand management/behavioural change: improved public transport/NMT and facilities for walking and cycling coupled with disincentives for private car usage.	Reduces emissions of both types of pollutant.

Source: Adapted DEFRA (2007)

Achieving Co-Benefits in Sub-Saharan Africa

The CDM has the potential to contribute further to achieving co-benefits, especially in the transport sector. This is beneficial to both the developed and developing countries participating in the project because synergies between global carbon abatement goals and local sustainable development goals are exploited. In addition, the CDM may contribute to several developing country development objectives, including:

- increased energy efficiency and conservation;
- transfer of technologies and financial resources;
- local environmental benefits, e.g. cleaner air and water;
- local environmental co-benefits, such as health benefits from reduced local air pollution;
- poverty alleviation and equity considerations through income and employment generation;
- sustainable energy production; and

- private and public sector capacity development.

Given the wide range of possible measures SSA cities may be inclined to select and implement a measure depending on a number of factors. These include geographic and socio-economic characteristics, environmental concerns, sources of air pollutants and GHGs, political and stakeholder commitment, current laws and regulations, social preferences, abatement costs, risks associated with the implementation of the measure, financial concerns, and technical barriers. Measures selected should be the result of a transparent, consultative and participatory decision-making process, taking into account these factors.

Low Cost Options for Greenhouse Gas Emissions

Implement measures to achieve co-benefits in the reduction of urban air pollutants and greenhouse gas emissions

Many measures of air pollution reduction also reduce GHG emissions. Such measures include cleaner production technologies, cleaner fuels and vehicles, and demand management of goods and services.

Use the of CDM as a vehicle to implement co-benefit measures

The use of the CDM can lead to increased energy efficiency and conservation; transfer of technologies and financial resources; local environmental and human health benefits. Subsequent benefits will include sustainable energy production; private and public sector capacity development; and poverty alleviation and equity realisation through income and employment generation.

7.6 Implementation in Sub-Saharan Africa

A good overall environmental policy, supported by all responsible government departments, can lead to sound and rational AQM in SSA countries. AQM should be seen as an objective for sustainable development. The implementation of a sound and rational AQM within the overall policy framework, as well as in specific policies such as land use planning, energy, transport and industrial development, will reduce the adverse impacts of air pollution on human health and the environment. An integrated AQM process can inform, educate and train all stakeholders and strengthen stakeholder participation in all aspects related to air quality, e.g. adverse health and environmental impacts, prevention and reduction of air pollution.

There should be an increased commitment to AQM and its enforcement from all stakeholders, strengthening the legal basis of AQM in national laws and regulations and strengthening the capacity of responsible agencies to effectively enforce AQM policies. Existing international and regional guidelines, conventions and treaties related to AQM, transboundary air pollution and global climate change should be adopted and implemented. These will reduce the threats emerging from air pollution (e.g. the adoption of WHO Air Quality Guidelines as a long-term goal and interim ambient standards based on local conditions, experience and capabilities). Strengthening regional cooperation and sharing information on all aspects of air quality will help to solve both national and supranational challenges.

Table 7.8: Measures to achieve co-benefits

Transport	The transport sector is a major contributor to air pollution in SSA cities. Measures which could have the co-benefit of reducing urban air pollutants and GHGs are listed below: • fuel switch from petrol/diesel to CNG or LPG; • fuel switch from petrol/diesel to (sustainable) biofuels (impact on air pollutants uncertain); • public transportation policies (e.g. bus public transport); • traffic management, such as flyovers, separated traffic lanes, or improved roads; • vehicle policies, such as scrap and technical control programmes; • vehicle efficiency improvements; • fuel cell or hybrid/electric cars. Transport projects are particularly effective in achieving co-benefits. However, the development and approval of baseline and monitoring methodologies is an important step for implementation of such projects. With regard to the use of biofuels several methodologies have been (re)submitted and are awaiting approval by the CDM EB. However, for other transportation technologies this is not the case.
Industry and Power Production	Relocation is an effective measure to reduce urban air pollution from industry and power plants. However, this has no effect on GHG emissions and regional air pollution. In addition, flue gas treatment can reduce energy efficiency and lead to an increase in CO_2 emissions. Measures which can be applied to plants in or near urban areas exist, which also have co-benefits include: • fuel switch from coal to gas; • fuel switch from coal to biomass (reduces SO_2 emissions, and where the baseline is open biomass burning close to a city it also mitigates PM emissions); • energy efficiency measures; • (Non biomass) renewable energy; • cleaner coal technology, such as integrated gasification combined cycle or CO_2 capture and storage (where air pollutants are reduced in addition to CO_2). In the industry and power sectors many project types are already being implemented, such as energy efficiency, biomass utilisation and fossil fuel switch, thereby contributing to the improvement of urban air quality. For cleaner coal technologies one baseline methodology was approved in October 2007, thus increasing the opportunities for these technologies which have a larger co-benefit potential.

Table 7.8: Measures to achieve co-benefits

Buildings Sector	Several options for co-benefits exist in the residential and service sector exist. These include: • fuel switch from coal to gas in building heating (including district heating); • fuel switch from coal to (sustainable) biomass for heating/cooking; • in case baseline biomass utilisation is unsustainable: fuel switch from biomass to gas in cooking stoves or heating; • improved cooking stoves; • renewable electricity (e.g. solar home systems); • insulation of buildings to reduce energy consumption; • energy efficiency measures such as efficient lighting. In the buildings sector several project types can contribute to achieving better air quality. With regard to district heating, combined heat and power (CHP) as well as natural gas utilisation can be used and several such projects have already been implemented. Smaller scale projects such as renewable energy at the household level, improved cooking stoves and energy-efficient lighting are being developed but only one baseline and monitoring methodology has been approved as of June 2007 (distribution of energy efficient light bulbs to households).

Setting of targets and establishing indicators for acceptable air quality in SSA countries can improve the quality of the air, thereby reducing impacts on human health and the environment. WHO Air Quality Guidelines may be used in setting standards and averaging times. The criteria for the derivation of air quality guidelines set by WHO are also valid for setting standards. Experience from developed countries may be used to collect information on the number of standard exceeding values not leading to adverse health or environmental effects.

The provision of sufficient information and transparency in standard setting procedures ensures that stakeholders understand the environmental, health and socio-economic impacts of such standards. A participatory approach in setting standards which involves stakeholders (e.g. industry, local authorities, NGOs, media and the general public) will ensure assures social equity or fairness to all the parties involved. Strengthening the commitment and role of the media can assist in identifying air quality-related problems at an early stage. They can assist in communicating this information to the general public and outlining the necessary action required.

Regulations on emission standards for mobile and stationary sources, air quality standards, viable dispersion models and reliable monitoring procedures will ensure rational and sound AQM. This includes, where appropriate, the adoption of emission standards based on developed countries' experiences. Best available control technology avoids the problem of inequities among countries and prevents 'social dumping'.

A regular review of AQM policies and legislation such as updating emission and air quality standards and assessing the success and efficiency of AQM measures is recommended. The establishment of an accredited body for evaluation of the efficiency of programmes related to AQM can help in this assessment.

Regulations for frequent reporting of policy enforcement of AQM will give politicians and managers responsibility for the implementation of the necessary information to define the next steps in AQM.

Establishing national and regional accredited agencies for verification of data on emissions, dispersion models (and their outputs), air pollutant concentrations and health and environmental parameters will lead to data of known quality and enhanced reliability of information. While collaboration and information sharing in AQM issues among all responsible agencies is the best means to achieve the AQM goals at minimal cost.

Clean Air Implementation Plans (CAIPs) are a means of improving urban air quality and are a convenient way of reporting on the different activities in AQM, such as:

- estimating and/or monitoring emissions;
- dispersion modelling;
- air quality monitoring;
- testing compliance with emission and air quality standards;
- outlining measures to reduce emissions from mobile, stationary and area sources; and
- surveillance of health and environmental impacts.

The adoption of CAIPs as instruments for implementing effective environmental policy can assist in achieving policy goals in a structured and transparent manner. CAIPs have been adopted and successfully implemented in developed countries

Tailored for developing countries and countries in transition, they could include:

- a rapid assessment of the most important sources;
- monitoring results from a minimal set of air pollutant concentration monitors;
- simulation of the spatial distribution of air pollutant concentrations, using simple dispersion models;
- comparison with air quality standards;
- assessment of adverse health and environmental impacts;
- control measures to address pollution from mobile, stationary and area sources and their costs; and
- assessment of the internal and external costs and benefits of AQM.

CAIPs contribute to public information and awareness raising. CAIPs with rapid assessment procedures are especially suited for countries and cities with relatively little AQM capacity and where no established procedure exists for AQM. It is advantageous to:

- implement the CAIPs in incremental steps, tailored to the goals, policies, needs, capabilities and resources available in the country;
- validate the data for CAIPs through a national accredited body;
- make information from CAIPs widely available; and
- select an air quality champion for the dissemination of AQM information.

7.7 Summary

Table 7.9 provides a summary of low cost policy instruments for AQM in SSA.

Table 7.9: Summary of low cost policy instruments for air quality management

Component	Objective	Low Cost Option	Description
Industry	To implement strategies to reduce urban industrial emissions,	Ban the import of obsolete technologies from developed countries	Technologies imported in developing countries should follow the same state-of-the-art technology in developed countries in order to avoid health and environmental impacts that will be more costly to sort out once the technology is installed.
		Set limits on the sulphur content of imported coal	Sulphur content of imported coal should be below 1 per cent. A low sulphur content in fuels reduces SO_2 and sulphate emissions. The sulphur content of coal does not influence the price on the world market
		Desulphurization of the flue gases	Flue gas desulphurisation in scrubbers is the most cost-effective methods to reduce SO_2 emissions in existing power plants and industrial boilers. The polluter pays principle would mean that the owner of the facility would have to cover the costs.
		Use of a two stage combustion; flue gas recirculation; and reducing combustion preheat temperature and low excess air to reduce NO_x emissions	This is a cost-effective method to reduce NO_x emissions in existing gas- or oil-fired plants. This is essentially a change to operating procedures. The polluter pays principle also applies.
		Increased energy efficiency in production to reduce overall energy demand leading to lower fuel consumption and lower emissions.	Enhanced energy efficiency leads to better combustions and consequently lower emissions of gaseous air pollutants.

Table 7.9: Summary of low cost policy instruments for air quality management (cont/)

Component	Objective	Low Cost Option	Description
Transport	To implement strategies to reduce urban motor vehicle emissions.	Traffic management	Traffic management measures include computerised traffic light control, network and junction design, parking controls, reducing the supply of space allocated to car parks, speed limits, avoiding obstacles leading to acceleration- and deceleration driving, restricted access for non-essential traffic, bus priority lanes, pedestrian areas and cycling facilities.
		Regulation and control of public bus transport	Use of efficient and comfortable public transport systems can help reduce transport emissions by reducing use of private vehicles. High standards of quality of service need to be implemented.
		Segregated lanes	Segregated lanes can help smooth the traffic flow thus reducing emissions.
		Non-motorized transport (NMT)	NMT is cycling and walking and serves to reduce short-distance car trips which are most polluting. Segregated lanes for motorized and NMT are necessary.

Table 7.19: Summary of low cost policy instruments for air quality management (cont/)

Component	Objective	Low Cost Option	Description
		Ban the import of obsolete vehicles and phase-out old vehicles still circulation.	Many vehicle fleets in SSA cities are older than 14 years. Obsolete vehicles which would not be licensed anymore in their countries of origin emit 10 times more air pollutants than newer vehicles. A low cost option is to not allow the import of obsolete vehicles and phase-out old vehicles already in circulation.
		Physical restraint	Physical restraints on vehicle use may take the form of limiting use of vehicles on specific days or in specific areas provided public transport facilities exist.
		Parking policies	Parking policies including Park and Ride Systems are likely to reduce both congestion and the demand for individual motorized transport. Effective enforcement of parking restrictions is necessary.
		Road pricing	Tolls on roads and motorways and congestion charges for the access to urban areas help limit car movement provided viable alternatives exist and under pricing is avoided.
		Use of low sulphur fuels in vehicles	The use of low sulphur fuels in vehicles, particularly diesel-driven ones reduces the emission of ultra fine sulphates which are a serious threat to human health because due to their carcinogenic properties.

Table 7.19: Summary of low cost policy instruments for air quality management (cont/)

Component	Objective	Low Cost Option	Description
Area	To implement strategies to reduce urban emissions from areas sources such as forest fires, burning of biomass and open burning of waste.	Ban deliberate open burning in urban areas and at municipal waste deposits.	A ban of open burning in urban areas helps reduce pollutant emissions. A collection, expert deposition and/or treatment must exist in order to enforce the ban
		Burn municipal and industrial hazardous wastes in existing cement plants at high temperatures.	Hazardous wastes must be treated before deposition of their residues. Municipal waste incinerators are expensive due to the high temperatures of incineration needed. Cement plants use incinerating temperatures high enough to burn most hazardous wastes and produce non-hazardous ashes and residues.
		Collection and use of used tyres as fuel in tar and lime production facilities if they exist or processed in cement kilns.	Open burning of used tyres in urban areas and on waste deposits leads to high emissions of PM and should therefore be avoided. Their incineration in tar and lime production facilities or cement kiln avoids this problem.

Table 7.19: Summary of low cost policy instruments for air quality management (cont/)

Component	Objective	Low Cost Option	Description
All sources		Using WHO air quality guidelines to set air quality standards.	The WHO air quality guidelines(AQG) can be utilized for setting air quality standards (AQS) in a country because the criteria for the derivation of AQG values are also valid for setting AQS. Use of the WHO AQG values to set AQS is a low cost option for developing countries in SSA.
		Use of a simple integrated model for air quality management.	The Simple Integrated Model for Better Air Quality (SIM-AIR) is a relatively new interactive model to examine emissions, ambient air quality and health.
Transboundary	To implement strategies to reduce emissions which contribute to: regional haze from forest fires, atmospheric brown cloud (ABC), acid deposition, regional dust and importation of hazardous waste.	Use of low-sulphur fossil fuels (low sulphur coal and oil, and natural gas).	Combustion of low sulphur fuels in industries and motor vehicles reduces the emission of ultra fine sulphates which are a serious threat to human health.
		Use of low excess air NO_x burners in industries can help to reduce NO_x emissions during combustion.	This is a cost-effective method to reduce NO_x emissions in existing gas- or oil-fired plants and is essentially a change in operating procedures. The polluter pays principle should always apply but in the case of transboundary pollution agreements among countries are needed.

Table 7.19: Summary of low cost policy instruments for air quality management (cont/)

Component	Objective	Low Cost Option	Description
		Use of flue gas desulphurisation and denitrification to remove the pollutants from flue gas.	New plants to be installed in SSA countries should employ state-of-the-art technology as in developed countries with respect to desulphurisation and denitrification in order to avoid cost-intensive *a posteriori* measures or be forced to accept human health and environmental impacts.
		Ban the importation of hazardous chemicals and hazardous wastes by implementing Amendment Decision III/1 to the Basel Convention and the Bamako Convention.	A ban on the importation of hazardous chemicals and hazardous wastes from developed to SSA countries avoids the 'social dumping' of hazardous materials which cannot be properly treated in developing countries. Thus, all SSA countries should adopt Amendment Decision III/1 to the Basel convention and the Bamako convention.
		For vehicle emission reduction, low sulphur fuels and NO_x control devices can be applied.	The use of low sulphur fuels in vehicles, particularly diesel-driven ones reduces the emission of ultra fine sulphates. NO_x control devices (catalysts) reduce NO_x emissions and limits O_3 chemical conversion. A prerequisite for effective NO_x control is the supply of fuels of appropriate quality and existence of an enforced I&M system.

Table 7.19: Summary of low cost policy instruments for air quality management (cont/)

Component	Objective	Low Cost Option	Description
Climate Change	To implement strategies to reduce greenhouse gas emissions which contribute to global climate change	Implement measures to achieve co-benefits in the reduction of urban air pollutants and GHG emissions	Many measures of air pollution reduction also reduce GHG emissions. Such measures include cleaner production technologies, cleaner fuels and vehicles, and demand management of goods and services.
		Use the Clean Development Mechanism (CDM) as an instrument to implement co-benefit measures	The use of the CDM can lead to increased energy efficiency and conservation; transfer of technologies and financial resources; local environmental and human health benefits. Subsequent benefits will include sustainable energy production; private and public sector capacity development; and poverty alleviation and equity realisation through income and employment generation.

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Annex 1

Definition of SSA regions

Region	Country
Eastern Africa	Burundi Comoros Djibouti Eritrea Ethiopia Kenya Madagascar Malawi Mauritius Mozambique Rwanda Seychelles Somalia Uganda United Republic of Tanzania Zambia Zimbabwe
Central Africa	Angola Cameroon Central African Republic Chad Congo, Republic of the Democratic Republic of the Congo Equatorial Guinea Gabon
Northern Africa	Algeria Egypt Libyan Arab Jamahiriya Morocco Sudan Tunisia Western Sahara
Southern Africa	Botswana Lesotho Namibia South Africa Swaziland
Western Africa	Benin Burkina Faso Cape Verde Cote d'Ivoire Gambia Ghana Guinea Guinea-Bissau Liberia Mali Mauritania Niger Nigeria Senegal Sierra Leone Togo