Division 44
Water, Energy, Transport

Air Quality Management

Module 5a

Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities

– revised October 2009 –

gtz Transport Policy Advisory Services

On behalf of
Federal Ministry
for Economic Cooperation
and Development

OVERVIEW OF THE SOURCEBOOK

Sustainable Transport:

A Sourcebook for Policy-Makers in Developing Cities

What is the Sourcebook?

This *Sourcebook* on Sustainable Urban Transport addresses the key areas of a sustainable transport policy framework for a developing city. The *Sourcebook* consists of more than 26 modules mentioned on the following pages. It is also complemented by a series of training documents and other material available from http://www.sutp.org (and http://www.sutp.cn for Chinese users).

Who is it for?

The *Sourcebook* is intended for policy-makers in developing cities, and their advisors. This target audience is reflected in the content, which provides policy tools appropriate for application in a range of developing cities. The academic sector (*e.g.* universities) has also benefited from this material.

How is it supposed to be used?

The *Sourcebook* can be used in a number of ways. If printed, it should be kept in one location, and the different modules provided to officials involved in urban transport. The *Sourcebook* can be easily adapted to fit a formal short course training event, or can serve as a guide for developing a curriculum or other training program in the area of urban transport. GTZ has and is still further elaborating training packages for selected modules, all available since October 2004 from http://www.sutp.org or http://www.sutp.cn.

What are some of the key features?

The key features of the *Sourcebook* include:

- A practical orientation, focusing on best practices in planning and regulation and, where possible, successful experiences in developing cities.
- Contributors are leading experts in their fields.
- An attractive and easy-to-read, colour layout.
- Non-technical language (to the extent possible), with technical terms explained.
- Updates via the Internet.

How do I get a copy?

Electronic versions (pdf) of the modules are available at http://www.sutp.org or http://www.sutp.cn. Due to the updating of all modules print versions of the English language edition are no longer available. A print version of the first 20 modules in Chinese language is sold throughout China by Communication Press and a compilation of selected modules will be sold by McMillan, India, in South Asia from June 2009. Any questions regarding the use of the modules can be directed to sutp@sutp.org or transport@gtz.de.

Comments or feedback?

We would welcome any of your comments or suggestions, on any aspect of the *Sourcebook*, by e-mail to sutp@sutp.org and transport@gtz.de, or by surface mail to:

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65726 Eschborn, Germany

Further modules and resources

Further modules are under preparation in the areas of *Financing Urban Transport*, *Transport and Health* and *Parking Management*.

Additional resources are being developed, and Urban Transport Photo CD-ROMs and DVD are available (some photos have been uploaded in http://www.sutp.org – photo section). You will also find relevant links, bibliographical references and more than 400 documents and presentations under http://www.sutp.org, (http://www.sutp.cn for Chinese users).

Modules and contributors

(i) *Sourcebook Overview and Cross-cutting Issues of Urban Transport* (GTZ)

Institutional and policy orientation

1a. *The Role of Transport in Urban Development Policy* (Enrique Peñalosa)

1b. *Urban Transport Institutions* (Richard Meakin)

1c. *Private Sector Participation in Urban Transport Infrastructure Provision* (Christopher Zegras, MIT)

1d. *Economic Instruments* (Manfred Breithaupt, GTZ)

1e. *Raising Public Awareness about Sustainable Urban Transport* (Karl Fjellstrom, Carlos F. Pardo, GTZ)

Land use planning and demand management

2a. *Land Use Planning and Urban Transport* (Rudolf Petersen, Wuppertal Institute)

2b. *Mobility Management* (Todd Litman, VTPI)

Transit, walking, and cycling

3a. *Mass Transit Options* (Lloyd Wright, ITDP; Karl Fjellstrom, GTZ)

3b. *Bus Rapid Transit* (Lloyd Wright, ITDP)

3c. *Bus Regulation & Planning* (Richard Meakin)

3d. *Preserving and Expanding the Role of Non-motorised Transport* (Walter Hook, ITDP)

3e. *Car-Free Development* (Lloyd Wright, ITDP)

Vehicles and fuels

4a. *Cleaner Fuels and Vehicle Technologies* (Michael Walsh; Reinhard Kolke, Umweltbundesamt – UBA)

4b. *Inspection & Maintenance and Roadworthiness* (Reinhard Kolke, UBA)

4c. *Two- and Three-Wheelers* (Jitendra Shah, World Bank; N. V. Iyer, Bajaj Auto)

4d. *Natural Gas Vehicles* (MVV InnoTec)

4e. *Intelligent Transport Systems* (Phil Sayeg, TRA; Phil Charles, University of Queensland)

4f. *EcoDriving* (VTL; Manfred Breithaupt, Oliver Eberz, GTZ)

Environmental and health impacts

5a. *Air Quality Management* (Dietrich Schwela, Stockholm Environment Institute)

5b. *Urban Road Safety* (Jacqueline Lacroix, DVR; David Silcock, GRSP)

5c. *Noise and its Abatement* (Civic Exchange Hong Kong; GTZ; UBA)

5d. *The CDM in the Transport Sector* (Jürg M. Grütter)

5e. *Transport and Climate Change* (Holger Dalkmann; Charlotte Brannigan, C4S)

Resources

6. *Resources for Policy-makers* (GTZ)

Social and cross-cutting issues on urban transport

7a. *Gender and Urban Transport: Smart and Affordable* (Mika Kunieda; Aimée Gauthier)

About the author

Dr Dietrich Schwela was educated as a physicist. In 1974 he began work at the State Air Pollution Centre of the State of Northrhine Westphalia, Germany. During this time he gathered vast experience on strategies and tactics of air quality management including emissions inventories; dispersion modelling; concentration inventories; effects of air pollution on humans, plants and materials; and environmental impact assessment. In collaboration with medical institutes, he planned and statistically evaluated epidemiological studies within the framework of the clean air implementation plans. In Spring 1994, Dr Schwela joined the World Health Organization in Geneva as air pollution scientist in the Occupational and Environmental Health Programme. He was responsible for the normative work of WHO in air pollution and health including guidelines for outdoor and indoor air quality, guidelines for community noise, health guidelines for vegetation fires, guidance for biological agents in the indoor environment, and for capacity building in air pollution and health in the Member States of the WHO. Since April 2005 he has been with the Stockholm Environment Institute working in the "Implementing Sustainability Group".

Additional contributions

Adriaan (Henk) van der Wiele is a chemist with over twenty-two years experience in assessing and managing environmental impacts of industrial projects both in Australia and internationally. He has extensive experience with the Western Australian Environmental Protection Authority. Henk was an Air Quality Adviser to the Indonesian Government, aiding the development of capability for air quality management, and has variously worked elsewhere in Middle East and Asia Pacific Region. Henk is now a partner and principal consultant in an environmental consultancy.

Module 5a

Air Quality Management

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1. Introduction

1.1 Objectives of the module

This module serves to assist policy-makers and their advisers in developing countries to determine the best measures to abate air pollution with limited information. The material presented draws upon knowledge gained from countries worldwide and provides practical advice to developing countries on how to develop legally enforceable air quality standards and simplified clean air implementation plans.

The module provides advice on which legal aspects need to be considered, how adverse effects in the population at risk can be defined, how exposure-response relationships can be applied, and how acceptable levels of risks can be assessed. It also describes where advice on the health effects of air pollution under different geographical, social, economic and cultural conditions can be found and how the capability for implementing air quality standards may be strengthened. The module discusses the factors which need to be considered in urban air quality management and provides guidance on urban air quality management provided by national, supranational and international agencies, programs and projects.

1.2 Overview

There are four major issues in urban areas related to ambient air pollution that may affect the health of people:

- Air pollution by chemical contaminants and biological agents;
- Greenhouse gas emissions and climate change;
- Environmental noise pollution;
- Radiation and electromagnetic fields.

Air pollution by chemical contaminants occurs both in the outdoor and indoor environment, with a dominance of exposure in the indoor environment where people spend most of their time. Air pollution by biological agents plays a role mostly in the indoor environment. Environmental noise pollution, radiation, and electromagnetic fields also play a role in the outdoor and indoor environment. In this module we concentrate on outdoor air pollution by chemical compounds. Noise pollution is considered in *Sourcebook* Module 5c: *Noise and its Abatement*.

Nowadays air pollution should be considered within a framework of climate change management (CCM) since both greenhouse gas (GHG) and air pollutant (AP) emissions are closely interlinked. GHGs and APs share the same sources — transport, industry, commercial and residential areas. CCM has two components: mitigation, *i.e.* GHG reduction, and adaptation. While GHG mitigation must be the foremost aim of CCM adaptation has become important as the effects of GHG emission, *i.e.* climate change is already observable. In this module air quality management (AQM) proper will be considered, however, always with the viewpoint of CCM.

The aim of local urban AQM is to protect public health and the environment from the damaging effects of air pollution, and to eliminate or reduce to a minimum human exposure to hazardous pollutants. In developed countries AQM has used sophisticated instruments to determine the necessary measures to control polluting sources. This has taken the form of clean air implementation plans, based on an evaluation of the most efficient methods to reduce air pollution. In contrast, an assessment of the air pollutant reduction measures in developing countries is typically based on more limited information concerning local sources, the dispersion of air pollution, actual air pollutant levels and related adverse effects. In particular, the lack of emissions inventories and the lack in the enforcement of emission and air quality standards makes the assessment difficult.

2. Basic facts

2.1 Importance of air pollution management

The importance of air pollution management follows from the following observations. In the Member States of the European Environmental Agency substantial percentages of urban dwellers are exposed to PM_{10}, NO_2 and O_3 concentrations above the EU limit and target values, see Table 1 and Figure 1.

In contrast the percentage of the urban population exposed to SO_2 concentrations above the EU limit is very small; however it should be noted that the new WHO 24-hour SO_2 guideline value (20 µg/m³) is less than ⅙ of the EU limit value.

The situation and the stressing factors in the developing regions of Latin America, Asia, and Africa are sketched in Boxes 1, 2 and 3.

Box 1: Air pollution in Latin America

Outdoor air pollution in urban areas of Latin American cities is perceived a serious problem. Elevated concentrations in megacities such as Sao Paulo or Mexico City sometime lead to the closure of industries, restricted use of motor vehicles, and transfer of industrial sources to more remote areas. The emissions of particulate matter, sulfur dioxide, nitrogen dioxide, and ammonia, and the corresponding outdoor concentrations of these compounds and, correspondingly, the levels of ozone have progressively increased in recent decades. In Mexico City, ozone levels are above the Mexican ozone standard of 360 micrograms per cubic metre for most days of the year.

The projections of the increases of the populations, the growth of industrialisation and private traffic appear to indicate a tendency of increase of 1990 concentrations for sulfur dioxide and particulate matter levels by 100–200% for Central America, the north of South America, the north of Chile and Argentina. For the south and east of Brazil, the increase could amount to about 300–400% of the 1990 values. These projections relate to increases in the number of vehicles and industrial combustion plants. If the development proceeds according to these estimates, it is projected for 2050 that the air pollution situation will be similar to or even worse than that of the United States and Europe in the sixties of last century.

Source: Adapted from SEI/Sida 2002a

Table 1: Urban percentages of the population in Europe potentially exposed to air pollution between 1997 and 2007

Air pollutant	Urban percentage (%)	EU limit/target value (µg/m³)	Averaging time	EU limit reference
PM_{10}	20–50	50	24 hours	EC (1999)
NO_2	13–41	40	Year	EC (1999)
O_3	14–62	120	Maximum daily 8–hour	EC (2002)
SO_2	< 1	125	24 hours	EC (1999)

Source: EEA (2009a)

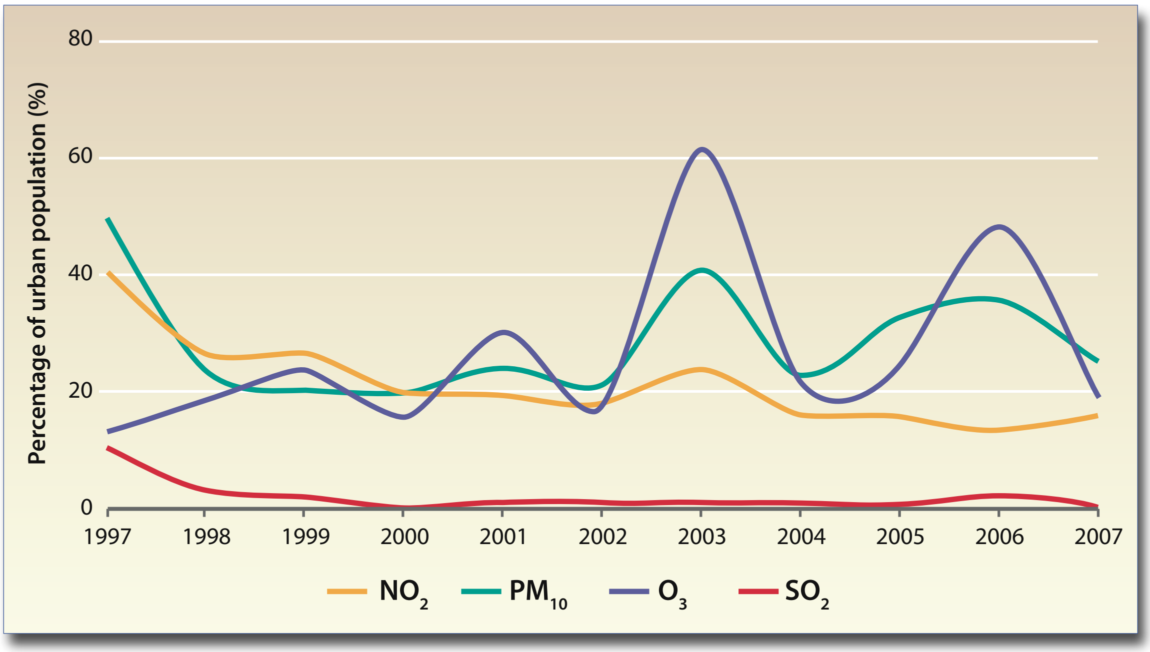


Figure 1
Percentage of urban population resident in areas where pollutant concentrations are higher than selected limit/target values, EEA member countries, 1997–2007.
Source: EEA (2009a)

Box 2: Air pollution in Asia

In Asia, rapid urbanisation, with the associated growth in industry and transportation systems, has increased regional concerns with regard to emissions of particulate matter, sulfur oxides, nitrogen oxides, and ozone. In some countries lack of urban planning controls has enabled industrial sources of air pollution to be built and often in close proximity to densely populated residential areas. Lack of monitoring equipment, assessment techniques and criteria, as well as legal frameworks for enforcement, mean that pollution can reach critical levels in cities in some developing countries. Emissions from stationary sources of air pollution are supplemented by emissions from mobile sources which exacerbate the problem (*e.g.* mopeds, motorcycles, motorised rickshaws (tuk-tuks), cars, buses and lorries).

The primary man-made source of particulate matter, sulfur and nitrogen in the Asia-Pacific region is fossil fuel combustion in the energy, industry and transportation sectors. The use of low quality fuel, inefficient methods of energy production and use, the poor condition of vehicles and traffic congestion are the major causes of increasing emissions of these gases. Emitted compounds have the capacity to be transported over large distances, sometimes hundreds of kilometres, and may give rise to depositions in another country. The potential for such transboundary air pollution was evident in the recent Indonesian forest fires. The area affected by the air pollutants from the fire spread for more than 3,200 km, east to west, covering six Asian countries and affecting around 70 million people. In the Malaysian State of Sarawak, the levels of particulate matter (PM_{10}) hit record levels of more than 900 micrograms per cubic metre (more than 18 times above the 2006 WHO guideline for PM_{10}). There is a need for regional intergovernmental co-operation.

Adapted from SEI/Sida 2002b; Schwela *et al.*, 2006

Box 3: Air pollution in Africa

In Africa urbanisation and industrialisation have increased regional concerns with regard to emissions of particulate matter and nitrogen oxides. According to projections, if African countries continue to develop along a 'conventional development pathway' at predicted rates, by the mid-21st century their emissions of sulfur will exceed projected levels in Europe and the USA. A major and growing source of particulate matter and nitrogen pollution across Africa is the combustion of fossil fuels in the power generation and smelting industries. In South Africa, one of the most industrialized countries in Africa, impacts of acid rain have already been reported on forests, crops and surface waters. Air pollution in urban centres in Southern Africa has been linked to human health impacts. Household and industrial energy consumption across the continent is predicted to increase by over 300% during the next fifty years with consequent significant growth in sulfur and nitrogen emissions. Emitted pollutant gases have the capacity to be transported over large distances, sometimes many hundreds of kilometres, and may give rise to depositions in other countries.

Source: SEI/Sida 2002c; Schwela, 2007

Air pollution in mega–cities: Sao Paulo (1), Kuala Lumpur (2), Cairo (3, 4).

Karl Fjellstrom, 2002

Box 4: Air pollution fatalities now exceed traffic fatalities by 2 to 1

Excerpt from Earth Policy Institute, Eco-Economy Update, http://www.earth-policy.org/Updates/Update17.htm, CAI-Asia list, September 2002.

The World Health Organization estimates that 2.5 million* people now die each year from the effects of air pollution. This is three times the 1 million who die each year in automobile accidents. A study published in The WHO in 2006 estimated that outdoor air pollution in France, Germany, Italy, Poland, Spain and the UK is responsible for more than 45,000 deaths annually in those six countries. About half of these deaths can be traced to air pollution from vehicle emissions.

Governments go to great lengths to reduce traffic accidents by fining those who drive at dangerous speeds, arresting those who drive under the influence of alcohol, and even sometimes revoking drivers' licenses. But they pay much less attention to the deaths people cause by simply driving the cars. While deaths from heart disease and respiratory illness from breathing polluted air may lack the drama of deaths from an automobile crash, with flashing lights and sirens, they are no less real.

* Source: WHO 2004; 2006

Recent estimates of the increase in daily mortality show that on a global scale 3–6% of premature deaths each year are due to exposure to PM in the ambient and indoor environment, with potentially 800,000 excess deaths annually due to PM outdoor concentrations, and about 1.6 million excess deaths annually due to PM indoor concentrations (WHO, 2006). Moreover, approximately 20–30% of all respiratory diseases appear to be caused by ambient and indoor air pollution, again with an emphasis on the latter (Schwela, 1996; 2000a; b).

Although enormous progress has been made in air quality management and clean air implementation plans for urban areas, especially in developed countries, a substantial number of people living in urban areas—approximately 1.5 billion, or 25% of the global population—are still exposed to enhanced concentrations of gaseous and particulate pollutants in the air they breathe. In addition, the use of open fires for indoor cooking and heating currently exposes approximately 2 billion people to substantial concentrations of suspended particulate matter, 10—20 times higher than outdoor concentrations. Sources of outdoor air pollution include industrial, commercial, and vehicular emissions, as well as vegetation fires. Furthermore, population growth in low-income countries is placing stress on already inadequate infrastructures and technical and financial capacities. In parallel,

Box 5: Potential health benefits of reducing particulate matter in Jakarta, Indonesia

One recent study illustrated the potential impact on human health of air pollution reduction, through the use of exposure benefit relationships. (An exposure benefit relationship is the quantitative relationship between the amount of exposure to a substance and the extent of toxic injury or illness produced.) Data from exposure-response relationships, observed in developed countries were applied to local conditions to assess the annual benefits of reducing airborne pollution to meet both Indonesian standards and WHO guidelines.

Health benefits of reducing particulates in Jakarta to Indonesian standards

Presenting the impacts of air pollution in physical terms (number of people with illnesses or dying) can be a powerful way to prompt government action, as well as providing a basis for cost-benefit calculations for different policy measures.

The estimated numbers of lives saved and illnesses avoided in a population of 8.2 million that could be achieved if Jakarta complied with Indonesian particulates standards was as follows:

Health endpoint	Estimate
Premature mortality	1,200
Hospital admissions	2,000
Emergency room visits	40,600
Restricted activity days	6,330,000
Lower respiratory illness	104,000
Asthma attacks	464,000
Respiratory symptoms	31,000,000
Chronic bronchitis	9,600

Such numbers are a powerful means to prompt government action, as well as providing a basis for cost benefit estimates for chosen policies.

Jakarta figures based on Ostro 1994

the process of urbanisation will continue, such that the proportion of the global population living in cities will increase from approximately 43% in 1990 to around 60% by the year 2030, see Figure 2 (UN, 2008), creating dense centres of anthropogenic emissions.

This is also reflected in the increase in the number of megacities, mostly in developing countries:

- 1990: 68 cities with more than 3 mn people;
- 2009: 88 cities with more than 4 mn people (City Population, 2009);
- 2025: 43 cities with more than 8 mn people (UNESA, 2007).

Human health studies show that air pollution in developing countries accounts per year for hundreds of thousands of excess deaths, millions of limited activity days and billions of dollars in medical costs, see Box 4 (WHO, 2006). These losses, and the associated degradation in quality of life, impose a significant burden on all sectors of society, but especially the poor. World Bank studies in Jakarta, for example, estimated dose response relationships to health outcomes (Box 5).

2.2 Major types of air pollutants

Major types of air pollutants include particulate matter (PM_{10}, $PM_{2.5}$) including the ultrafine black carbon particles, ozone carbon monoxide, nitrogen oxides, volatile organic compounds and hydrocarbons, and photochemical oxidants such as ozone. Table 2 exhibits selected pollutants and their major sources and effects, while Table 2 shows pollutants typically associated with some typical engine and fuel combinations.

In developing cities, however, the most critical air pollutants are particulate matter and ozone. Several recent studies on the air pollution situation of cities in developing countries exist (Schwela *et al.,* 2006; Baldasano, 2003; Molina and Molina, 2004; Gurjar *et al.,* 2008; Atash, 2007).

With respect to particulate matter the most commonly reported indicator is the concentration of PM_{10} (particles with an equivalent aerodynamic diameter less than 10 µm). In many Asian cities the PM_{10} annual mean concentration exceeds 100 µg/m^3 with the maximum levels above 200 µg/m^3 (Oanh *et al.,* 2006; Kan *et al.,* 2008; Vichit-Vadakan *et al.,* 2008; Qian *et al.,* 2008). In Asian cities, a decrease in PM_{10} concentrations was experienced between 1997 and 2006 (Schwela *et al.,* 2006; CIA-Asia, 200). A similar trend and a reduction in PM_{10} levels were seen in cities of Central and South America between 1995 and 2004 (Cifuentes, 2005).

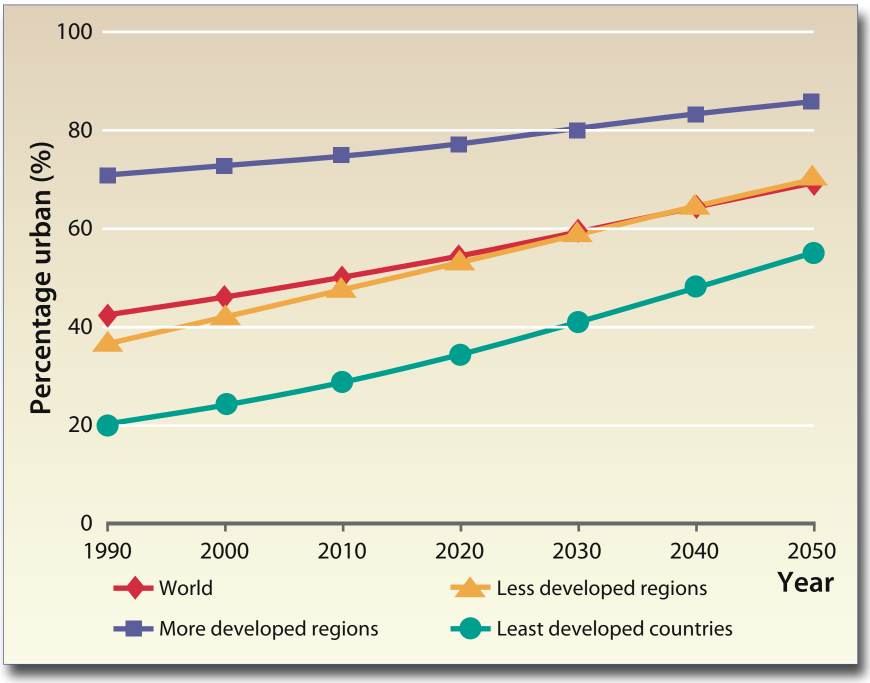


Figure 2
Percentage of urban populations in the world, more developed regions, less developed regions and least developed regions.
Source: UN (2008)

Before the phase-out of lead in gasoline high values of lead were observed in many cities, *e.g.* in Dhaka up to 14.6 µg/m^3 averaged over the period November 1995 to January 1996 (UNEP/WHO/SEI/KEI 2002b). Nowadays since unleaded fuel is used in almost all countries, concentrations are less than 0.2 µg/m^3 (WHO 1995a; UNEP/WHO/SEI/KEI 2002a; b; Begum & Biswas, 2008; Hopke *et al.,* 2008).

When compared with WHO guideline values (WHO, 2006) the air pollutant concentrations in major and megacities of developing countries reach levels of concern for public health (see Table 2).

2.3 Classification of health effects of air pollutants on various compartments of the human body

The health impacts of air pollutants are numerous and varied and can become manifest in any compartment of the human body. Compartments affected include the respiratory system, immune system, skin and mucous tissues, sensory system, central and peripheral nervous system, and the cardiovascular system.

Table 2: Sources of air pollution, effects and World Health Organization guidelines for selected pollutants

Pollutant	Major sources	Effects	Health guidelines (WHO 2002a)
Carbon monoxide (CO)	Motor-vehicle exhaust; some industrial processes	Poisonous to humans when inhaled. CO reduces the oxygen carrying capacity of blood and places additional strain on the heart and lungs	10 mg/m^3 (10 ppm) over 8 hrs; 30 mg/m^3 over 1 hr (30,000 µg/m^3)
Sulphur dioxide (SO_2)	Minor contribution from mobile sources. Heat and power generation facilities that use oil or coal containing sulphur; sulphuric acid plants	A human irritant, SO_2 undertakes atmospheric reactions to contribute to acid rain	20 µg/m^3 over 24 hrs; 500 µg/m^3 over 10 min
PM_{10} particulate matter	Soil, oceanic spray, bush fires, domestic burning, motor vehicles, industrial processes and organic dusts from plant material	Contributes to haze, increases cancer risk, mortality effects, aggravates respiratory illnesses	50 µg/m^3 over 24 hrs; 20 µg/m^3 annual mean
$PM_{2.5}$ particulate matter			25 µg/m^3 over 24 hrs; 10 µg/m^3 annual mean
Lead (Pb)	Added to some fuels, Pb is emitted from motor-vehicle exhaust; lead smelters; battery plants	Affects intellectual development in children; many other adverse effects	0.5 µg/m^3 over a year
Nitrogen oxides (NO, NO_2)	A side effect of high combustion temperatures causing bonding of nitrogen and oxygen in motor vehicle exhaust; heat and power generation; nitric acid; explosives; fertilizer plants	Irritant, precursor to photochemical smog formation	200 µg/m^3 over 1 hr for NO_2; 40 µg/m^3 annual mean
Photochemical oxidants (primarily ozone [O_3]; also peroxyacetyl nitrate [PAN] and aldehydes)	Formed in the atmosphere by reaction of nitrogen oxides, hydrocarbons, and sunlight	An irritant, Photochemical oxidants contribute to haze, material damage, and, aggravates respiratory illnesses	100 µg/m^3 over 8 hrs

Source: WHO (2006)

Table 3: Summary of pollutant types and emissions for some typical engine and fuel combinations

Engine Type	Fuel Type	Vehicle Type	Major Emissions
4-Stroke cycle	Gasoline	Cars (also trucks, aircraft, motorcycles)	HC, CO, NO_X
Diesel	Diesel Oil	Trucks, buses, tractors (also cars)	NO_X, SO_X, soot, particulates
2-Stroke cycle	Gasoline/oil mixture	Motorcycles, outboard motors	HC, CO, particulates
Gas turbine	Jet	Aircraft, marine applications	NO_X, particulates

Health effects of air pollution on the respiratory system (lower airways, see Figure 3) include acute and chronic changes in pulmonary function, increased incidence and prevalence of respiratory symptoms, sensitisation of airways to allergens, and exacerbation of respiratory infections such as rhinitis, sinusivitis, pneumonia, alveolitis, and legionnaires' disease. Principal agents for these health effects are the combustion products SO_2, NO_2, PM_{10} and CO. In addition, indoor air pollutants—fine PM from environmental tobacco smoke (ETS), formaldehyde, and infectious organisms—can also act as important agents.

Health effects of air pollution on immune system allergies manifest themselves in exacerbation of allergic asthma, allergic rhino-conjunctivitis, extrinsic allergic alveolitis/hypersensitivity pneumonitis, and can produce permanent lung damage in sensitised individuals including pulmonary insufficiency. Principal agents are known to be outdoor allergens and indoor air agents such as house mite dust, cockroaches, organisms living in the pelt of pets, insects, and moulds in high humidity environments. Multi-centre studies have shown different spatial patterns of allergic disease (*e.g.* asthma, rhinitis and eczema) as well as allergic hyper-sensitisation. These variations cannot be reconciled by geographical differences in allergen exposure since the major aeroallergens are widespread. Health effects of air pollution on the skin and on mucous tissues (eyes, nose, throat) are mostly

Box 6: Health effects in children

In 1990, the World Summit for Children was convened in order to address the desire to provide a better future for every child in the world. For the Summit, UNEP and UNICEF published the 1990 *Children and the Environment* report, with the message that "environmental degradation is killing children." This theme recognises that a clean, healthy environment is the first step toward providing a better future for children. However, in the years that have passed since the Summit and the publication of the report, many problems have persisted while others have arisen.

Children are especially vulnerable to the adverse effects of air pollution because of their physical characteristics and their childhood behaviour. Children's intake of contaminants is greater than that of adults because per unit of body weight, they eat, drink, and breathe more, and their surface area to volume ratio is nearly three times that of an adult. Body functions, such as detoxification, metabolic changes, and excretion of toxins are also different than those in adults. The immune system, nervous system, and organs of children are not yet fully developed. All these impacts may lead to permanent damage.

Children of low income families often live in areas with high levels of air pollution. Many children live within a close distance, if not on top of, former or even present toxic waste dumps. Moreover, the urban poor often live very near to highways or the urban industrial sector, thus being exposed to the pollutants that are emitted from heavy traffic and polluting industries. In fact, in the urban slum areas of Bangladesh, lead levels in the air are three times greater than WHO air quality guidelines.

UNEP/UNICEF 1990; CICH 2000; UNEP/UNICEF/WHO 2001; 2002

irritating effects. Primary sensory irritations include dry—sore—throat, tingling sensation of nose, and watering and painful eyes. Secondary irritation is characterised by oedema and inflammation of the skin and mucous membranes up to irreversible changes in these organs. Principal agents include volatile organic compounds, formaldehyde and other aldehydes (*e.g.* acetaldehyde, acrolein) and ETS.

Sensory effects of air pollution include nuisance and annoyance reactions caused by perception of

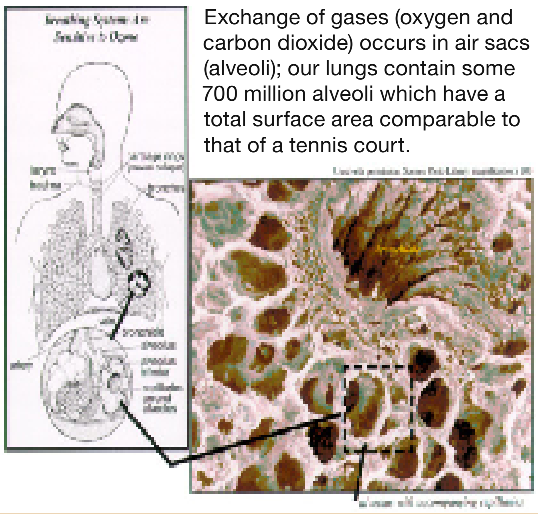


Figure 3
The respiratory system.
Source: Science Library

air pollutants through sensory organs. VOCs, formaldehyde and ETS can act as principal agents.

Effects of air pollution on the central nervous system manifest themselves in damage of the nerve cells, either toxic or hypoxic/anoxic. Principal agents are VOCs (acetone, benzene, toluene, formaldehyde), CO and pesticides. In infants and young children, neuro-physiological changes caused by Pb can result in developmental retardation and irreversible deficiencies.

Effects of air pollution on the cardiovascular system develop through reduced oxygenation and result in increased incidence and prevalence of cardiovascular diseases, myocardial infarction, and consequent increase in mortality caused by cardiovascular diseases. Principal agents are CO, PM and ETS.

Carcinogenic effects of air pollution are associated with lung cancer, skin cancer, and leukaemia. Principal agents for lung cancer have been identified as arsenic, asbestos fibres, chromium, nickel, cadmium, polycyclic aromatic hydrocarbons (PAH), trichloroethylene, ETS and radon. Benzene is known to produce leukaemia, and ultraviolet radiation is a causative agent of skin cancer. A difficult and largely unresolved question is that of synergism among the different carcinogenic compounds and between carcinogenic and non-carcinogenic agents.

The health impacts of lead are especially serious in children because lead affects the body during the crucial development. Children are known to develop learning disabilities and intelligence quotients decrease (see Box 6).

Box 7: Noise pollution

The noise problems of modern societies are characterised by an immense number of cars and heavily laden lorries with diesel engines in cities and the countryside, particularly in developing countries. Health problems may be quite substantial, including physical stress, hearing impairment, and exacerbation of cardiovascular disease.

The extent of the noise problem in developing countries is large. Noise levels alongside densely traveled roads in Bangkok, Thailand, were found to amount to 75 to 80 dBA for 24 hours (WHO 2000b). In a study in Karachi, Pakistan, it was observed that about 83% of street policemen had noise induced hearing loss. The same study reported noise induced hearing loss in 33% of rickshaw drivers and 57% of shopkeepers in a busy bazaar.

WHO 2000b

2.4 An emerging issue: noise

In comparison with other pollutants, environmental noise has always been an underestimated environmental problem (see Box 7). The control of environmental noise, is, however, important as some health endpoints are influenced by both noise and air pollution (Schwela *et al.,* 2003). In addition, the inclusion of noise issues in air quality management has been hampered by insufficient knowledge of its effects on humans and of dose-response relationships as well as a lack of defined criteria. From both perspectives, practical actions to limit and control exposure to environmental noise are essential (see *Sourcebook* Module 5c: *Noise and its Abatement*). The WHO *Guidelines for Community Noise* were published in 2000 (WHO, 2000c); subsequently WHO expert groups discussed night time noise guideline values which were published in October 2009 (WHO, 2009). The WHO guidelines for community noise cover also issues of noise assessment and management and could help cities to address challenges of increasing noise levels. There are many other agencies involved with noise (Schwela and Smith, 2007). A strategic approach for environmental noise management in developing countries has been recently developed (Schwela & Finegold, 2009).

3. Air Quality Management

3.1 Introduction

Basic principles guide international and national policies for the management of all forms of air pollution. An important global initiative occurred in 1983 when the UN General Assembly established the World Commission on Environment and Development. The report produced by the Commission, Our Common Future, was endorsed by the UN General Assembly in 1987. It has been influential in bringing environmental issues into the global arena, and in expressing influential concepts in air quality management (WCED 1987) (see further *Sourcebook* Module i: *Sourcebook Overview and Cross-cutting Issues of Urban Transport*).

The Brundtland Commission suggested that sustainable development would be required to meet the legitimate aspirations of the world population without destroying the environment. It defined ***sustainable development*** as: "***development that meets the needs of the present without compromising the ability of future generations to meet their own needs***." This concept has been embraced as an apparent means of integrating environmental policy and economic development.

Following the Brundtland Commission, the UN Conference on the Environment and Development was held in Rio, in 1992 (UNCED 1992). The aim was to ensure that practical foundations for sustainable development were put in place. The *Agenda 21* document and the Rio declaration were the most obvious results of this conference. *Agenda 21* is a document covering sustainable development, which is not binding on countries. However, national implementation is reviewed by the Sustainable Development Commission and the UN General Assembly. *Agenda 21* supports a number of environmental management principles on which some government policies are based, including air quality management. These include:

- The ***precautionary principle***—where it is clear that a proposal will damage the environment, action should be taken to protect the environment without awaiting scientific proof of damage.

- The ***polluter pays*** principle—the full costs associated with pollution (including monitoring, management, clean-up and supervision) should be met by the organisation or person responsible for the source of the pollution.

In addition, many countries have adopted the principle of ***pollution prevention***, which aims to reduce pollution at sources.

Agenda 21 states in Chapter 6 on 'human health and environmental pollution' that nationally determined action programs in the area of urban air pollution, with international assistance, support and coordination where necessary, should include (UNCED 1992):

I. Develop appropriate pollution control technology on the basis of risk assessment and epidemiological research for the introduction of environmentally sound production processes and suitable safe mass transport.

II. Develop air pollution control capacities in large cities, emphasizing enforcement programs and using monitoring networks, as appropriate.

Ten years after Rio, the World Summit on Sustainable Development (WSSD) recognised the problem of air pollution in Section IV 39 of its Plan of Implementation of the WSSD, which requests States to:

> "Enhance cooperation at the international, regional and national levels to reduce air pollution, including transboundary air pollution, acid deposition and ozone depletion bearing in mind the Rio principles, including, inter alia, the principle that, in view of the different contributions to global environmental degradation, States have common but differentiated responsibilities, with actions at all levels to:
>
> (a) Strengthen capacities of developing countries and countries with economies in transition to measure, reduce and assess the impacts of air pollution, including health impacts, and provide financial and technical support for these activities" (WSSD 2002).

The Plan acknowledges the significant impact of air pollution on human health in Section VI on Health and Sustainable Development which states:

> "49. Reduce respiratory diseases and other health impacts resulting from air pollution, with particular attention to women and children, by:
>
> (a) Strengthening regional and national programmes, including through public-private partnerships, with technical and financial assistance to developing countries;
>
> (b) Supporting the phasing out of lead in gasoline;
>
> (c) Strengthening and supporting efforts for the reduction of emissions, through the use of cleaner fuels and modern pollution control techniques;
>
> 56. Phase out lead in lead-based paints and other sources of human exposure, work to prevent, in particular, children's exposure to lead, and strengthen monitoring and surveillance efforts and the treatment of lead poisoning" (WSSD 2002).

By this, cities in both developed and developing countries are obliged to implement air quality management strategies to address the deterioration in urban air quality associated with high levels of population growth, urbanisation, industrial activity and motor vehicle use.

However, there is no universal air quality management strategy that could be applied to all cities throughout the world. Each urban area is unique in terms of its air pollution problems, spatial and temporal patterns of emission sources and cultural, economic, physical and social characteristics.

Whenever discussing air quality management in urban area two additional issues have to be considered: Transboundary air pollution and climate change.

The transboundary movement of air pollution across borders may cause adverse effects in countries other than the country of origin. Regional and transboundary air pollution has been a topic of scientific research for several decades and its importance has been increasingly recognised REFS. Pollutants with a potential for regional and, transcontinental and even hemispheric transport include fine and ultrafine particles, sulphur dioxide, nitrogen dioxide, carbon monoxide, ozone, volatile organic compounds, mercury, and persistent organic pollutants. Uncontrolled forest fires cause haze pollution often a thousand kilometres away from their location of origin. The "Atmospheric Brown Cloud" has been identified as a phenomenon of a 3 km thick blanket of pollution, which is composed of black carbon, sulphates, nitrates, mineral dust and fly ash (UNEP, 2008). Acid deposition includes both dry and wet (acid rain) deposition and is a serious environmental threat, particularly on the Northern Hemisphere. Dust from the Sahara regularly causes a number of high events of particulate matter in Europe and even reaches Central and South America. In Asia, the "yellow-sand" phenomenon consisting of dust of natural origin from desert areas of China and Mongolia is observed as a distinct yellow cloud on satellite imagery.

Climate change (CC) is considered to be one of the greatest challenges mankind faces today. The effects of global climate change become more and more evident (IPCC, 2007). Since 1906 the Earth's surface temperature has increased by approximately 0.74 °C. Most of the warming has occurred in recent decades and is very likely due to man-made emissions of greenhouse gases (GHGs) particularly from transport and industry (IPCC, 2007). Most GHGs are emitted from the same sources as APs. Their emissions interact in the atmosphere and cause a variety of direct (APs) and indirect (GHGs) health and environmental impacts. The spatial scales of urban APs and GHGs are, however, different. APs generally remain in the atmosphere for a relatively short period (days or weeks) while a GHG such as carbon dioxide has a lifetime of 150 years and methane approximately 12 years (DEFRA, 2007). The simultaneous mitigation of GHGs and APs can incur co-benefits for human health and the environment.

Several organizations have published guidelines and toolbooks on AQM. These include:

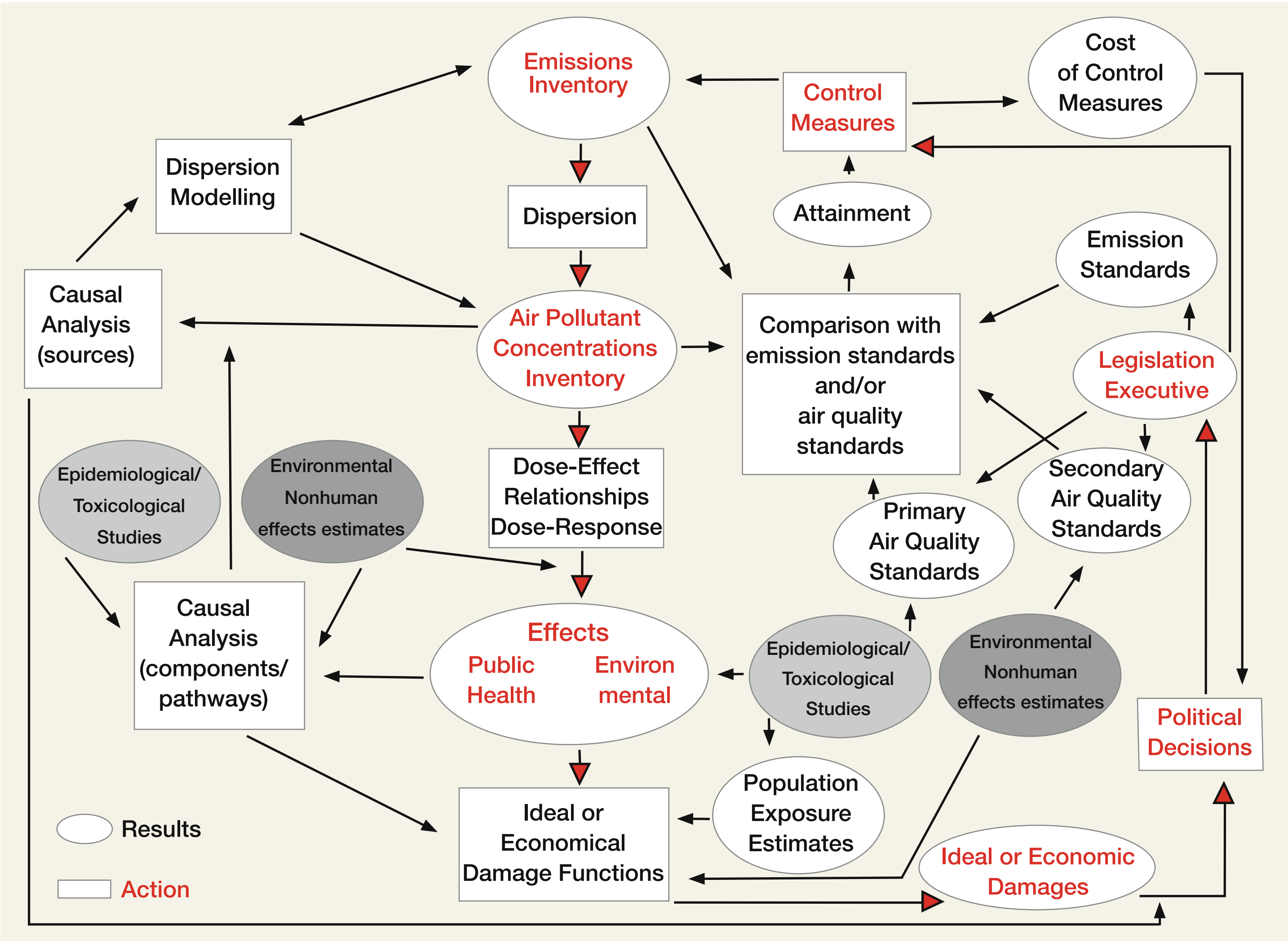
- World Bank (2004) Urban Air Pollution: Policy Framework for Mobile Sources;
- MIT (2004) Decision Support Tools for Urban Air Quality Management;
- UNEP/UNCHS (2005a; b) Urban Air Quality Managgement Toolbook and Toolkit;
- ADB (2006) Country/City Synthesis Reports on Air Quality Management in Asia;
- DEFRA (2008) Local Air Quality Management.

3.2 Towards a strategy for Air Quality Management

The goal of air quality management is to maintain a quality of air that protects human health and welfare. This goal also includes protection of animals, plants (crops, forests and natural vegetation), ecosystems, materials and aesthetics, such as natural levels of visibility (Murray 1997). And to achieve this air quality goal, it is necessary to develop appropriate air quality policies and strategies.

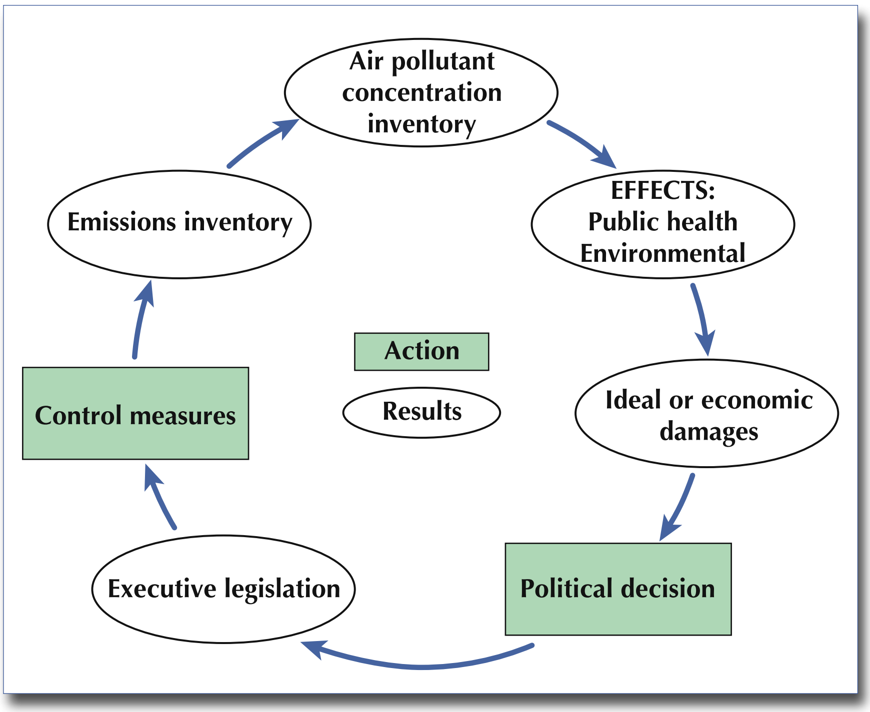
Government policy is the foundation for air quality management. A Strategic Framework for Air Quality Management in Asian Cities (SF, 2004) was developed by SEI in its Air Pollution in the Megacities of Asia (APMA) project in collaboration with the Clean Air Initiative for Asian Cities (CAI-Asia). Without a suitable policy framework and adequate legislation it is difficult to maintain an active or successful air quality management program. A policy framework refers to policies in several areas, including transport, energy, planning, development and the environment. Air quality objectives are more readily achieved if these interconnected government policies are compatible, and if mechanisms exist for co-ordinating responses to issues which cross different areas of government policy. Measures adopted in many developed countries for integrating air quality policy with health, energy, transport and other areas are summarised in a report of the United Nations Economic Commission for Europe (UNECE 1999).

The complete scheme of relevant interrelationships in air quality management is depicted in Figure 4. The complexity of this figure reflects the complexity of the task. Two aspects of Figure 4 should be emphasised. First, the scheme clearly indicates that air quality management has the ultimate goal of avoiding health and environmental impacts of air pollution. If man-made air pollution had no effects whatsoever, people would not care. Thus all the instruments developed in the course of the last fifty years such as emissions inventories, dispersion modelling, or concentrations inventories, only serve to enable decision makers to develop legislation and regulations needed to avoid detrimental effects on public health



Figures 4a and 4b

The scope of air quality management (above), and a simplified air quality management cycle (right).



and the environment. The instruments mentioned are, therefore, tactical tools in air quality management, while health and environmental preservation are to be grounded in goals and objectives of air quality management. Emissions inventories, concentration measurements, dispersion models and other tools of air quality management are, therefore, never end in themselves; the ends are human health and a healthy environment.

Second, data of known quality obtained from the tactical tools of monitoring and assessment in air quality management are only intended to generate information for decision makers and the public, which leads to political decisions and the formulation of policies appropriate to prevent adverse impacts of air pollution on human health and the environment. Also under this aspect of policy formation, health and environment have the prominent role of defining the objectives of policies and regulations. (It should be noted that the information necessary for politicians is created from "data of known quality" and not necessarily from data of high quality, which although most desirable cannot always be obtained under the conditions of many developing countries.)

The policy formation and decision support system aspects of air quality management will be taken up in Section 6 of this module. In the following paragraphs air quality assessment tools are considered in more detail. The main tools are:

- Emissions inventories/measurement;
- Outdoor monitoring;
- Dispersion models.

All three assessment tools are interdependent in scope and application. Accordingly, monitoring, modelling and emission assessments should be regarded as complementary components in any integrated approach to exposure assessment or determining compliance against air quality criteria.

A Foundation Course on Air Quality Management in Asia was developed by SEI which is for adult learners studying the issue without the support of a class room teacher (SEI, 2008). It has been compiled by an international team of air pollution specialists and aims to provide the student with a good grounding in the main issues relevant to each aspect of air quality management. It provides an opportunity to develop an understanding of the basic components required to formulate a programme to manage and achieve better urban air quality. The Foundation Course consists of six modules in conjunction with the Strategic Framework on Air Quality Management in Asia:

1. Urban Air Pollution in Asia
2. Emissions
3. Modelling
4. Monitoring
5. Impacts
6. Governance and Policies.

The Foundation Course was funded by the Asia Urbs Programme of the EuropeAid Co-operation Office and co-funded by the World Health Organization (WHO), the International Atomic Energy Agency (IAEA), the Norwegian Institute for Air Research (NILU), the Norwegian Agency for Development Cooperation (NORAD), and Force Technology Copenhagen.

3.3 Emission inventories

3.3.1 Introduction

A crucial component of an air quality management plan is a reasonable quantitative knowledge of the sources of the various emissions. An emissions inventory is essential. In some cases, emissions are described in source groups. These may be:

- ***Point sources*** such as stacks in major industrial sites (see Figure 5).
- ***Mobile sources*** such as on-road motor vehicles. Mobile sources are often considered as line sources as it is not practicable to consider the emissions from each car separately but rather to sum up the emissions along the road (considered as a line; see Figure 6).
- ***Area sources*** include open burning of waste materials from agriculture, forestry and land clearance. Other sources are forest fires, emissions from vehicle refuelling, off-road vehicles and marine craft, and commercial and domestic fuel combustion. Surface mining and overgrazing of land in semi-arid areas can also act as sources of particles. A typical area source is shown in Figure 7.

Biogenic or natural sources, such as deserts, eroded areas, agricultural emissions are a non-anthropogenic source category, mostly being to area sources.

3.3.2 Steps in constructing an emissions inventory

There is no single way to develop an emissions inventory. The following procedures have previously been implemented in developing countries, and could be considered as a model.

1. Assigning pollutant categories

These include:

- Pollutants that should be inventoried and for which data is readily available (commonly primary pollutants such as lead, and particulates);

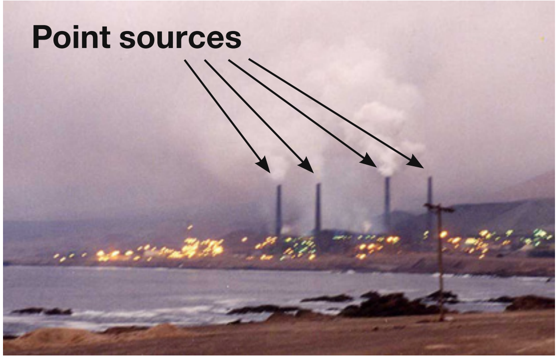


Figure 5
A copper smelter in Ilo Perú.
Dietrich Schwela, WHO

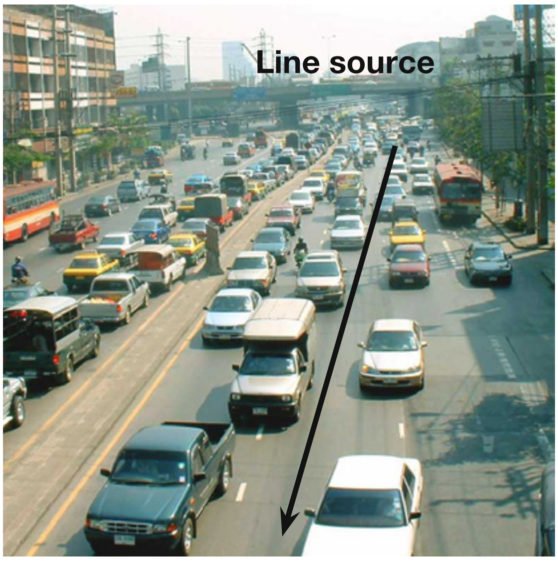


Figure 6
Traffic congestion in a street in Bangkok.
Karl Fjellstrom, 2002

- Pollutants that should be included but for which data is limited or not available;
- Secondary pollutants that are formed in the atmosphere, which can only be attributed to the concentrations of precursor sources by numerical models (such as ground level ozone).

2. Compiling the data

Constructing the inventory requires information on the source strength (the amount of emissions) of all emitters within a specified area. Five stages in calculating an emission inventory are generally recognized. These include:

- Establishing a list of point, area and mobile sources;
- Contacting and obtaining from plant operators quantitative estimates of point source emissions;
- Obtaining raw data and deriving activity data on such factors as the size and classification of the vehicle fleet, kilometres travelled and estimates for domestic fuel consumption;
- Reviewing data for validity and suitability
- Processing the individual source and activity level data to provide a spatially desegregated source inventory.

For some components of an emissions inventory accurate data may be available. For example, accurate emissions data may be available for some industrial sites from measurements of stack emissions. In other cases, emissions can be calculated from estimates of process inputs. For example, the emissions of SO_2 from coal-fired electricity generation plants can often be calculated with reasonable accuracy from the knowledge of the throughput and sulphur content of the fuels and other information.

Figure 7
Waste deposit in Lagos, Nigeria.
Dietrich Schwela, WHO

While estimates of emissions are needed to develop emission inventories, measurements to confirm the veracity of the estimates are highly desirable. Surveys may be used for point sources such as large industrial facilities to provide data on their emissions. However, reporting by companies is not always complete, particularly for fugitive emissions (such as leaks of volatile substances, equipment leaks and loss of fine particles from stockpiles), and for combustion products such as PAH for which sufficient data may not be available.

In some developing countries, reliable statistical information for producing reliable emissions estimates is lacking. However, where action is needed to improve air quality, the absence of this information should not prevent the development of preliminary emissions estimates on the basis of appropriate population, socioeconomic

Emission factors software

Vehicle emission factor models are software tools for predicting gram per mile (or kilometre) emissions of hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_X), particulate matter (PM) and air toxics from cars, trucks, and motorcycles under various conditions.

The German Federal Environmental Agency (http://www.uba.de) has recently developed a ***Handbook of Emission Factors***; a sophisticated modelling application applicable to various fleet characteristics and climatic conditions.

Spatial resolution of emissions inventories

In view of the abilities of the rapid techniques of WHO (*e.g.* WHO 1995b) and the PAHO/World Bank DSS IPC (see WHO/PAHO/WB 1995a) the emissions of the individual point and line sources can be estimated, and be classified by the individual emitters in a simplified way. The use of a one kilometre grid would only be appropriate for large area sources, and for the purpose of drawing maps of the emission density. For actual cost effective measures at point sources, the contribution of the individual sources is needed, estimated for example by DSS IPC. For motor vehicles the presentation as line sources is much more informative for policy-makers.

and traffic-related indicators. Basic information about the population, transportation, industry, fuels and other information can be used to calculate preliminary emissions estimates (Kato and Akimoto 1992) with corresponding potential transportation emission reductions measures. This information is also related to the application of transportation planning, traffic control, traffic regulation and other traffic management measures, which can reduce individual traffic emissions through mobility management measures (see *Sourcebook* Module 2b: *Mobility Management*). All these aspects are helpful to develop and implement air quality management or clean air implementation plans. Such preliminary emissions estimates can be revised as more accurate information becomes available.

3. Determining emission factors

Emission factors relate pollutant emissions to level of activity. Table 4 presents examples of activity level statistics from various sources.

When source data are missing, it is common to use general emission factors for both point and diffuse sources (Emissions from diffuse sources include emissions from motor vehicles and off-road mobile sources, and area sources such as light industry, domestic and wood burning, as well as biogenic emissions from natural sources such as vegetation.). Emission factors for diffuse sources are usually calculated using data specific for each source type. For example motor vehicle emissions may be estimated by calculations involving the distance travelled by vehicles, the number of vehicles, temperature, fuel consumption and the composition and properties of the fuels used.

Table 4: Examples of typical activity level statistics from various sources

Source	Pollutant	Activity level
Four-stroke gasoline vehicle	NO_X	grams of NO_X per km travelled
	CO	grams of CO per km travelled
Steam boiler	particulate	grams of particulate per tonne of steam produced
	NO_X	grams of NO_X per tonne of steam produced
Power generating plant	particulate	grams of particulate per kilowatt fired
	NO_X	grams of NO_X per kilowatt fired
Nitric Acid plant	NO_X	grams of NO_X per tonne of HNO_3 produced

General emission factors for various industrial processes are available from published sources (such as EEA (undated); (USEPA 1998; 2000a; b) and more recent supplements and updates). However, these emission factors need to be used with care, as adjustments in emission factors may be needed to take into account differences in operating conditions, fuels and feed materials.

Sources of information on how to prepare rapid emissions inventories include WHO 1993a; b; 1995; 1997 and, more recently, GAPF 2008. These include the use of emission factors for the car fleet in a city, which is classified by type and age of the vehicles, cylinder displacement, and catalytic converter, diesel filter and other emission-reducing equipment. Details on these issues can be found in WHO 1993a. WHO, in collaboration with the US Environmental Protection Agency has developed a *Teacher's Guide for Motor Vehicle Air Pollution* comprising a one week training workshop (WHO 1996), which covers all relevant topics including case studies in developing countries. Additional aspects are discussed in Section 6. The Global Atmospheric Pollution Forum (GAPF) has developed an Air Pollutant Emissions Inventory Manual and its associated software (an EXCEL-based workbook) with the help of regional air pollutant emissions experts from Africa, Asia, Europe and Latin America (GAPF, 2008). The purpose of the Manual is to provide a simplified and user-friendly framework for emissions inventory preparation that can be used in different developing and rapidly industrialising countries. The Manual is designed to be relevant for the regions, easy to use, compatible with other major international emissions inventory approaches, and to use principles of good practice in preparing inventories. Air pollutants included in the emissions inventory manual include SO_2, NO_X, PM_{10}, $PM_{2.5}$, NH_3, CO, NMVOCs and CO_2.

More sophisticated inventories of motor vehicle emissions include different control measures and allow evaluation of the effectiveness of a given regulatory program. Some of the more important factors to be included in a more comprehensive emissions inventory are:

- Emission factors envisaged for new vehicles;
- Deterioration of vehicle emissions with vehicle age and mileage;
- Tampering effects;
- Vehicle maintenance;
- Inspections and maintenance and anti-tampering checks;
- Vehicle miles travelled per vehicle and year;
- Vehicle misfuelling, fuel volatility and other fuel characteristics such as sulfur content, distillation characteristics and oxygen content;
- Ambient temperature.

Some details regarding these issues are given by Walsh 1999 and, more recently, in the EMEP/CORINAIR Emission Inventory Guidebook (EEA, 2007) and its substantial update, the EMEP/EEA Air Pollutant Emission Inventory Guidebook to be published in late 2009 (EEA, 2009).

Once the inventory has been completed it is important to conduct an emissions verification exercise to ensure that the accuracy and precision of estimates remain within acceptable parameters. Verification involves ascertaining the completeness and consistency of the data input and involves checks on:

- How definitions of sources and of pollutants have been applied;
- The completeness of the data entered for each sector, sub-sector and activity;
- The consistency of the inventory at different levels of spatial disaggregation;
- The transparency of the emissions inventory—whether the data inputs are fully traceable to their references.

Verification can also involve the use of dispersion and modelling studies to assess the inventory in relation to measured air quality.

3.4 Ambient air quality monitoring and assessment

3.4.1 Assessment tools and functions

The ultimate purpose of monitoring is not merely to collect data, but to provide the information necessary for scientists, policy makers and planners to make informed decisions on managing and improving the environment. Monitoring fulfils a central role in this process, providing the necessary sound scientific basis for policy and strategy development, objective setting, compliance measurement against targets and enforcement action (see Figure 4a and 4b).

However, the limitations of monitoring should be recognised. In many circumstances, measurements alone may be insufficient—or impractical—for the purpose of fully defining population exposure in a city or country. No monitoring program, however well funded and designed, can hope to comprehensively quantify patterns of air pollution in both space and time. At best, monitoring provides an incomplete—but useful—picture of current environmental quality. Monitoring therefore often needs to be used in conjunction with other objective assessment techniques, including dispersion modelling, emission measurement and inventories, interpolation and mapping.

Conversely, reliance on modelling alone is not recommended. Although models can provide a powerful tool for interpolation, prediction, and optimisation of control strategies, they depend on the availability of reliable emission data. A complete inventory for a city or country may need to include emissions from point, area and mobile sources; in some circumstances, assessment of pollutants transported into the area under study may also need to be considered. It is important, also, that the models utilised are appropriate to local conditions, sources and topography, as well as being selected for compatibility with available emission and meteorological datasets.

Inventories in developing cities will, for the most part, be estimated using emission factors appropriate to the various source sectors (verified by measurement), and used in conjunction with surrogate statistics such as population density, fuel use, vehicle kilometres or industrial throughput. Emission measurements will usually only be available for large industrial point sources, or from representative vehicle types under standardised driving conditions.

3.4.2 Monitoring objectives

The first step in designing or implementing any monitoring system is to define its clear, realistic and achievable monitoring objectives. Setting diffuse, overly restrictive or ambitious monitoring objectives will result in cost-ineffective programs with poor data utility. In such circumstances, it will not be possible to make optimal use of the available resources. Clear, realistic and achievable monitoring objectives include:

- Determining population exposure and health impact assessment;
- Informing the public about air quality and raising awareness;
- Identifying threats to natural ecosystems;
- Determining compliance with national or international standards;
- Providing objective inputs to air quality management, traffic and land-use planning;
- Source apportionment and identification;
- Policy development and prioritisation of management actions;
- Development/validation of management tools (models, geographic information systems, etc.);
- Assessing point or area source impacts;
- Trend qualification, to identify future problems or progress against management/control targets.

Clearly defined monitoring objectives enable appropriate data quality objectives to be defined. The following are the essential requirements to be met by measurements, if overall monitoring objectives are to be achieved:

- Measurement accuracy and precision;
- Traceability to metrology standards;
- Temporal completeness (data capture);
- Spatial representativeness and coverage;
- Consistency – from site to site and over time;
- International comparability/harmonisation.

In turn, this makes it possible for a targeted and cost-effective quality assurance program to be developed.

The relationships between the data collected and the information to be derived from it must be taken into account when a monitoring programme is planned. This emphasises the need for users and potential users of the data to be involved in the planning of surveys, not only to ensure that they are appropriate to their needs, but also to justify the resource commitment. It should be recognised that monitoring networks are invariably designed for a variety of functions. These may include policy and strategy development, local or national planning, measurement against international guidelines, identification/quantification of risk and public awareness.

3.4.3 Quality assurance and quality control (QA/QC)

Quality assurance and control (QA/QC) is an essential part of any air monitoring system. It is a program of activities that ensures that measurements meet defined and appropriate standards of quality, with a stated level of confidence. The function of QA/QC is to ensure that data are fit for the purpose. Major QA/QC objectives include:

- Measurements which are accurate, precise and credible;
- Data which is representative of ambient or exposure conditions;
- Results which are comparable and traceable;
- Measurements which are consistent over time;
- High data capture, evenly distributed;
- Optimal use of resources.

The functional components of a QA/QC program are identified in Table 5.

QA/QC systems are considered in greater detail elsewhere (UNEP/WHO 1994a; Bower 1997; Schwela 2003; SEI 2008) with respect to:

- Site operation;
- Site selection;
- Equipment education;
- Operator training;
- Laboratory QA;

Table 5: QA/QC for Air Monitoring: the major components

Quality Assurance	■ Definition of monitoring and data quality objectives. ■ Network design, management and training systems. ■ Site selection and establishment. ■ Equipment evaluation and selection.
Quality Control	■ Routine site operations. ■ Establishment of calibration/traceability chain. ■ Network audits and inter-calibrations. ■ System maintenance and support. ■ Data review and management.

- Point of measurement QA;
- The need for effective data screening and validation;
- Avoidance of spurious data collection.

3.4.4 Network design

There are no universal rules for network design, since any decisions will be determined ultimately by the overall monitoring objectives and resource availability. Although monitoring systems can have just a single, specific objective, it is more common for them to have a broad range of targeted program functions. No survey design can hope to completely address all the possible monitoring objectives listed in Section 3.4.2. However, the design of surveys to meet these individual requirements often has common features, and should use common data (to avoid duplication of effort) and overlapping data to verify the credibility of results and conclusions. The overall design goal is to ensure that the maximum information be derived from the given effort. Where networks may be operated by a variety of organisations, standardisation or at least harmonisation of the programs and sharing of data is vital to avoid unnecessary effort and to maximise overall cost-effectiveness.

A key issue, which needs to be addressed at a very early stage of the network design process, is that of resource availability. In practice, this is usually the major determinant in network design, which will exert a particularly strong influence on the choice of site numbers, pollutants to be monitored and instrumentation selected.

A wide range of commitments and costs is likely to be incurred in any air monitoring program, including purchase of analysers, equipment maintenance, staff costs, and running costs. Before any firm capital or resource commitment it is therefore essential to plan the survey, assess resource availability, select the most appropriate equipment and choose monitoring sites; *e.g.* if no monitoring has been performed in the past, municipalities should start with a simple network of not too sophisticated and expensive monitors such as diffusive tubes for gaseous compounds and DustTraks and minivols for particulate matter. The reason for this approach is that it does not make sense to use sophisticated and expensive automatic analysers in order to find out that an air pollution problem for a particular compound does not exist.

3.4.5 Site numbers and selection

For the purposes of designing a network to assess population exposure and compliance with air quality guidelines or standards, a number of basic issues need to be addressed including:

- Where is the population?
- What pollutant concentrations are they exposed to?
- …and for how long?
- In what areas and micro-environments is exposure important?

In practice, the number and distribution of air quality monitoring stations required in any network, or the number of samplers used in a survey, also depend on:

- Required data use/objectives;
- Area to be covered;
- Spatial variability of pollutants;
- Resource availability;
- Instruments deployed.

Once the type of a site is chosen—*e.g.* residential area, commercial area, industrial area, kerbside—the actual condition of the monitoring site is very important. Requirements should be considered in light of:

- Access (and potential vandalism);
- Site sheltering;
- Infrastructure (availability of electricity, telephone);
- Closeness to buildings;
- Free exposure to air stream;
- Adequate separation from sources or sinks.

These issues should be addressed in a detailed and transparent manner before steps for purchasing instruments are taken. Further advice on a number of approaches to network design and site selection is given in UNEP/WHO 1994a; WHO 2000a; Schwela 2003; EU 1996; 1999; 2000; 2002; 2004; 2008a).

3.4.6 Sampling strategies and systems

Monitoring involves assessing pollutant behaviour in both space and time. A good network design should therefore seek to optimise both spatial and temporal coverage, within available resource constraints (UNEP/WHO 1994a;

Bower 1997; Schwela 2003). Integrating measurement methods such as passive samplers, although fundamentally limited in their time resolution, are useful for the assessment of long-term exposure, as well as being invaluable for a variety of area-screening, mapping and network design functions (UNEP/WHO 1994b). Problems can arise, however, when using manual sampling methods in an intermittent, mobile or random deployment strategy.

When auditing monitoring sites world-wide, sampling system deficiencies are by far the most commonly encountered problem. Usually, these result from inappropriate designs or inadequate cleaning of the sampling system (see further UNEP/WHO 1994a; b; c; WHO 2000a; Schwela 2003).

3.4.7 Instrument issues

The capabilities of air monitoring methodologies, as well as their inevitable resource implications, exert a strong influence on network design. This section reviews some of these issues.

Air monitoring methodologies can be divided into four main generic types, covering a wide range of costs and performance levels. These are passive samplers, active samplers, automatic analysers and remote sensors. The main advantages and characteristics of these monitoring technologies are summarised in Table 6.

It is advisable to always choose the simplest technique that will do the job. Inappropriate, overly complex or failure-prone equipment can result in poor network performance, limited data utility and—worst of all—a waste of money. Although monitoring objectives are the major factor to consider, resource constraints and the availability of skilled manpower must also be considered. There is a clear trade-off between equipment cost, complexity, reliability and performance. More advanced systems can provide increasingly refined data, but are usually more complex and difficult to handle.

"Diffusive samplers … are the method of choice for developing countries just starting to implement air quality management."

Sampler methods are not necessarily less accurate than automatic analysers. In practice, the combined use of samplers and automatic analysers in a *hybrid* monitoring program can offer

Table 6: 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, mapping and baseline studies	■ Unproven for some pollutants ■ In general only provide monthly and weekly averages ■ Labour-intensive deployment/ analysis ■ Slow data throughput	US$10–70 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$1,000–3,000 per unit
Automatic analysers	■ Proven ■ High performance ■ Hourly data ■ On-line information	■ Complex ■ Expensive ■ High skill requirement ■ High recurrent costs	US$10,000–15,000 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$70,000–150,000 per sensor, or more

Source: UNEP/WHO (1994a)

a versatile and cost-effective approach to network design over a municipal or national scale. Such a network design will use passive or active samplers to provide good spatial coverage and area-resolution of measurements. Automatic analysers, deployed at carefully selected locations, can provide more detailed time-resolved data for assessing peak concentrations or comparison with short-term standards. Active samplers use pumps to draw air through an absorbing material. Active samplers have been widely used for decades in many countries of Europe, North America and elsewhere (Figure 8). The items of equipment needed for active sampling and analysis of several air pollutants are readily available, and are manufactured and serviced in many developing countries (UNEP/WHO 1994a; Schwela 2003; SEI 2008).

Passive samplers involve the collection of air pollutants without the use of pumps. There are many types of passive samplers, including bulk collectors, surrogate surfaces, flux samplers, semi-diffusive and diffusive samplers, and so on. Diffusive samplers are special passive samplers which collect gaseous air pollutants by molecular diffusion using absorbing material. Diffusive sampling will be especially useful for the following activities:

- Classification of zones;
- Preliminary assessment of ambient air quality;
- Tool for network design/optimisation;
- Air quality monitoring in areas at no risk of exceeding limit values;
- Determination of areas of homogeneous air quality;
- Assessment of personal exposure to relevant pollutants.

Diffusive samplers have many advantages but also some disadvantages compared to 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, diffusive samplers are usually the most cost-effective solution to a measurement problem, and are the method of choice for developing countries just starting to implement air quality management. Whereas active samplers present major siting problems due to noisy pumps, diffusive samplers are silent and small and therefore easy to site. Highly skilled personnel are not required on-site. 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, resulting in time-weighted average concentration measurements. This limitation, however, seems to be being mitigated by recent development of radial diffusive samplers, for example for ozone.

Figure 8

An active sampler being used for air quality surveys near a UK airport.

Courtesy Jon Bower, AEA Technology

The current state of the art of diffusive sampling technique for ambient measurements was presented in recent conferences organized by the European Communities (EC 2002), and the Royal Society of Chemistry, UK (RSC 2005; 2009).

Careful selection of monitoring sites and good mounting of diffusive samplers is vital in surveys using diffusion tubes, as illustrated for example in Figure 9.

3.4.8 Turning data into information

As emphasised in the introduction to this section, the purpose of monitoring is not merely to collect data, but to produce useful information for planning, health professional, regulatory and public end-users. Raw data by themselves are of very limited utility. These first need to be screened (by validation) and collated to produce

Figure 9
Protective shelters and good mounting are essential in passive sampler surveys.
Dietrich Schwela, WHO

a reliable and credible dataset (UNEP/WHO 1994a; Bower 1997; Schwela 2003). In effective Air Quality Management Information Systems, the validated measurements will be archived together with corresponding emission datasets, model predictions and other input relevant to decision-making.

The next stage in data management is analysis and interpretation, designed to provide useful information in an appropriate format for end-users. A variety of proven statistical methodologies are available for air quality datasets, including simple procedures such as calculation of averages, frequency distributions, percentile estimates and more sophisticated means such as correlation procedures, variance and regression analyses. However, the appropriate level and method of data treatment will be determined by the ultimate end-use. A minimum level of data management could be the production of daily, monthly and annual summaries, involving simple statistical and graphical analyses that show both time and frequency distributions of the monitoring data. The use of Geographic Information Systems should be considered, particularly when the intention is to combine pollution data with those from epidemiological and other geo-co-ordinated social, economic or demographic sources.

The information derived from measured data must be reported or otherwise disseminated in a timely manner to end-users. This should be in the form of complete datasets, processed summaries, peak or average statistics, exceedances of standards or targets, analytical results, graphs or maps. Formats for information transfer should be designed which are both appropriate to the capabilities of the network and to the requirements of the users.

3.4.9 Key pollutants and measurement methods

Measurement techniques available for determining ambient concentrations of the main "classic" pollutants, SO_2, NO_2, CO, O_3, SPM and lead have been described in UNEP/WHO 1994c; d; AEA 1996; WHO/SEARO 1996; WHO/PAHO 1997; BMU 1997; Schwela 2003; SEI 2008. More recently, key techniques were described in the SEI Foundation Course on Air Quality Management in Asia.

3.5 Air quality modelling

As indicated above, adequate understanding of emission, topography, meteorology and chemistry will allow the development of mathematical models for the prediction of pollutants, primary or secondary concentration, and accordingly prediction of impacts (ambient models). Other models estimate vehicle emission factors as functions of speed, ambient temperature, vehicle technology, and other variables.

Computer models developed so far include models for the prediction of air pollution concentration from single sources (***plume model***), in an air stream zone, a combination of stationary and mobile sources (***air stream model***) or in a geographical area at the downwind direction of a multiple sources, such as in cities (***long range transportation model***).

The simplest approach uses a point source dispersion model to estimate the ground-level concentrations of the pollutants of interest at some distance (typically from hundreds of metres to tens of km). More complicated models allow the examination of multiple sources, including area sources.

Dispersion modelling is a powerful tool for the interpolation, prediction and optimisation of control strategies. Models allow the consequences of various options for improving air quality to be compared. However, models need to be validated by monitoring data. Their accuracy depends on many factors, including the accuracy of the source emissions data, the quality of knowledge of meteorological conditions in the area, and the assumptions about physical and chemical processes in the atmosphere involving the transport and transformation of pollutants.

Dispersion models must be used in the following situations:

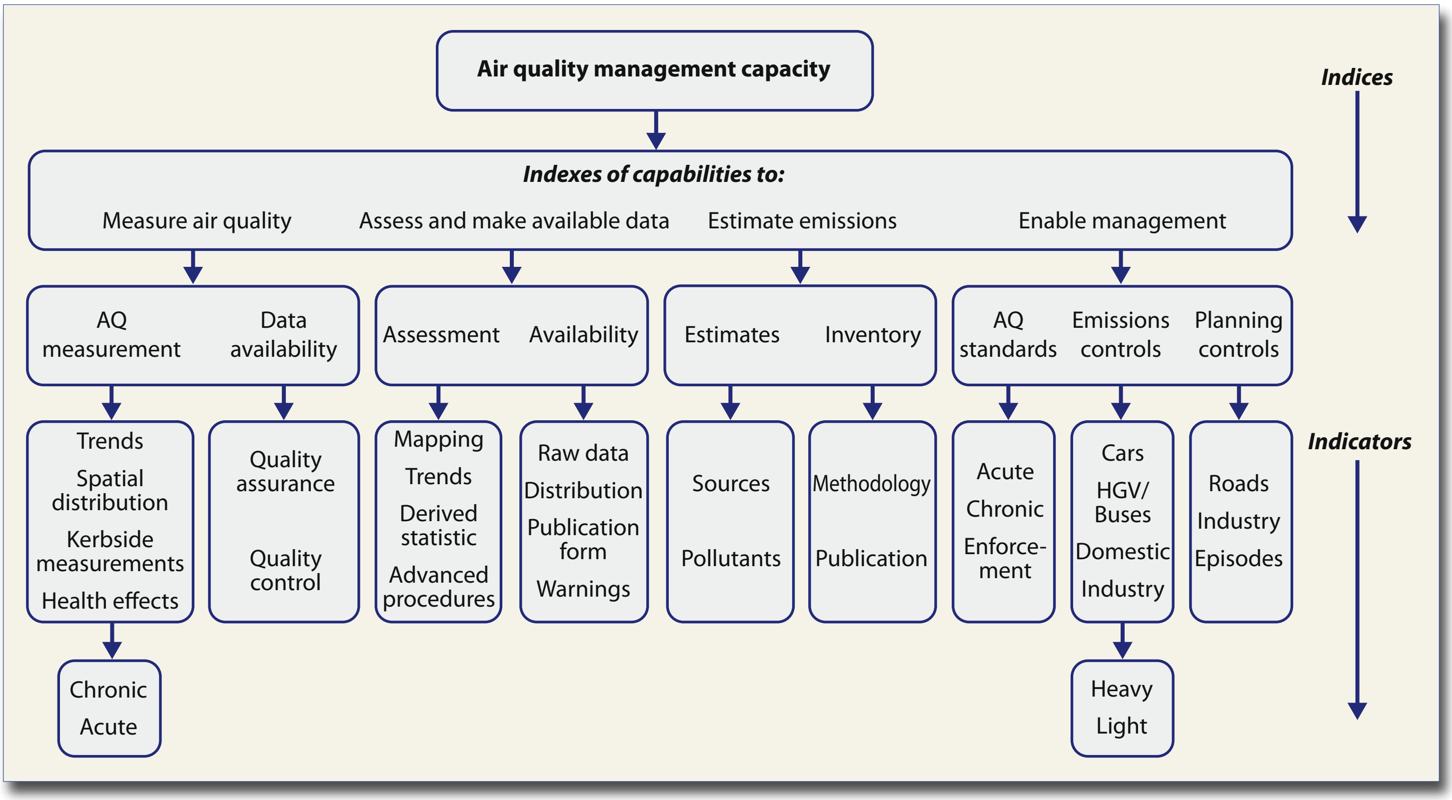
- An air pollutant cannot or is too expensive or difficult to be measured;
- A new or the modification of an existing facility is being planned in an urban area;
- Changes in traffic patterns in a city are being planned.

The results of dispersion modelling are typically maps showing the concentration of the considered pollutants (usually particulate matter, CO, O_3, NO_2, etc.) throughout the immediate area surrounding the facility point of origin. The United States Environmental Protection Agency and the European Environment Agency provide websites with urban dispersion models (US EPA 2002a; 2005; 2006a; EEA 2002; SEI 2008). A good practice guide for atmospheric dispersion modelling has been developed by the New Zealand Ministry for the Environment (MOE 2004).

3.6 Benchmarking of the capabilities of cities in Air Quality Management

In order to achieve an overall perspective of the air quality management capability of a city it is necessary to develop indicators to assess each component of capability. Once this has been done we can then group these component indicators together into an index of air quality management capability, which can be used to identify deficiencies and make comparisons of the air quality management capability of cities. Such an exercise has been performed by Schwela *et al.*, (2006) in a study on the capabilities of 20 Asian cities in air quality management. Four sets of capability indices were used which were adopted and adapted from a previous GEMS/AIR study (UNEP/WHO/MARC 1996). The indices to represent the principle components of management capability are:

Figure 10
Hierarchy of AQM Capability Indicators.
Source: Schwela *et al.*, (2006)



1. ***Index of air quality measurement capacity***—assessing the ambient air monitoring taking place in a city, and also the accuracy, precision, and representativeness of the data produced.
2. ***Index of data assessment and availability***—assessing how the air quality datasets are processed to enhance their value and provide information in a decision-relevant form. The index also assesses the extent to which there is access to the air quality information and data through different media.
3. ***Index of emissions estimates***—assessment of emissions inventories conducted to determine the extent to which decision-relevant information is available about the sources of pollution in the city.
4. ***Index of air quality management tools***—assessing the administrative and legislative framework through which emissions control strategies are introduced and implemented to manage air quality.

Each of these four sets of indices consists of a number of constituent indicators. For example, the air quality measurement capability index comprises the following indicators: the data validity (QA and QC); air quality measurements taken to determine trends and spatial distribution in pollutant concentrations and health effects, both chronic, and acute; and measurements taken of kerbside concentrations.

The hierarchy of AQM capability indicators is depicted in Figure 10.

The cities participating in this study were: Bangkok, Beijing, Busan, Colombo, Dhaka, Hanoi, Ho Chi Minh City, Hong Kong, Jakarta, Kathmandu, Kolkata, Metro Manila, Mumbai, New Delhi, Seoul, Shanghai, Singapore, Surabaya, Taipei and Tokyo. Representatives from the authorities of these cities provided the information for this assessment. Questionnaire responses were reviewed by external experts and have been cross-checked, where possible, with other available information to ensure that the information presented was correct. Each question was allocated a score. The more questions answered positively the greater the management capability of the city. Each index has a maximum score of 25 indicator points; by adding these together an overall assessment of capability is obtained with a maximum score of 100.

Table 7: Grouping of scores for the component and overall AQM capabilities

Effectiveness of capability	Component index score	Overall capability index score
Minimal	0 – ≤5	0 – ≤20
Limited	>5 – ≤10	>20 – ≤40
Moderate	>10 – ≤15	>40 – ≤60
Good	>15 – ≤20	>60 – ≤80
Excellent	>20 – ≤25	>80 – ≤100

Figure 11
Overall AQM capability.
Source: Schwela *et al.*, (2006)

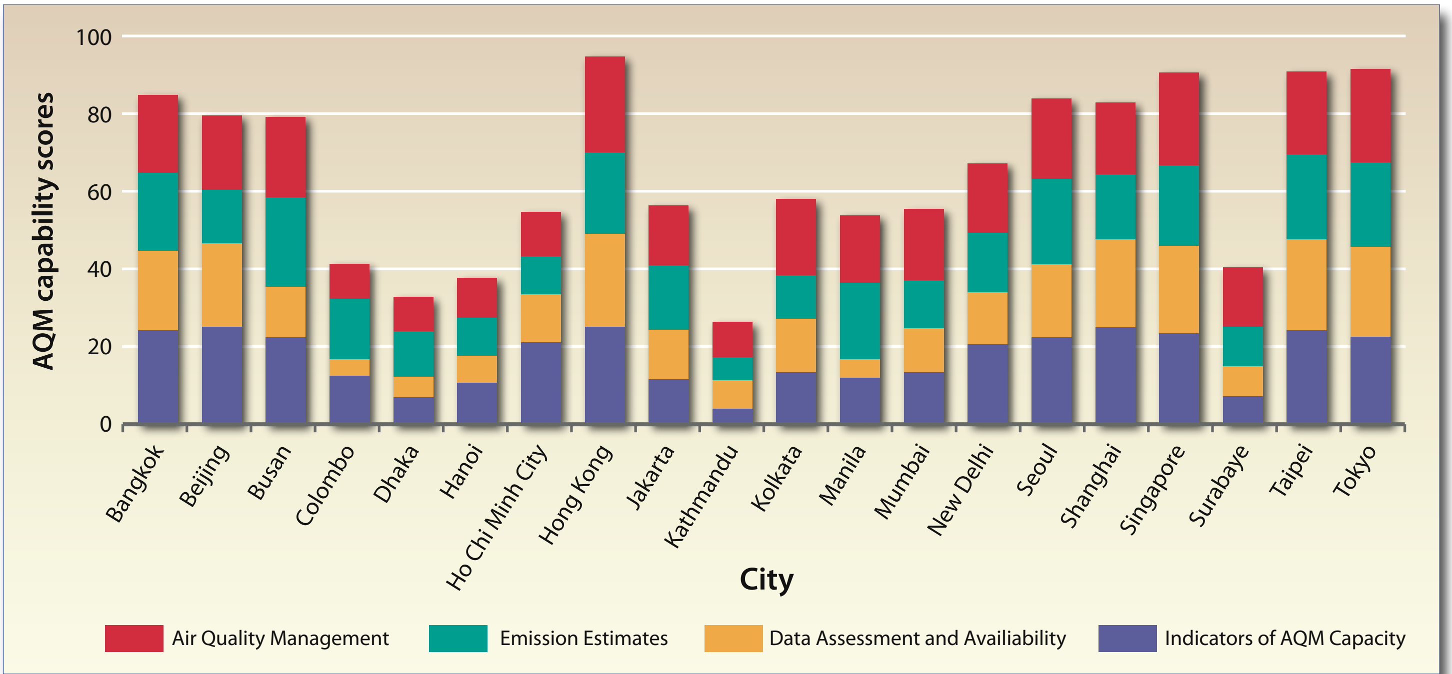


Table 7 presents the grouping of scores obtained into five bands of AQM capabilities.

An overview of the capacity of cities to formulate and implement AQM strategies is provided by combining the scores from the four component indices and shown in Figure 11.

A wide range of scores and capabilities exist within the 20 Asian cities. The overall performance is summarized in Table 8.

Table 8: AQM capability in 20 Asian cities

Overall capability	City
Excellent	Bangkok, Hong Kong, Seoul, Singapore, Shanghai, Taipei, Tokyo
Good	Beijing, Busan, New Delhi
Moderate	Colombo, Ho Chi Minh City, Jakarta, Kolkata, Metro Manila, Mumbai
Limited	Dhaka, Hanoi, Kathmandu, Surabaya
Minimal	None

The main points can be summarised as follows:

- Of the different components of management capability, developing cities generally possess the greatest capability to measure air quality. 11 out of the 20 cities participating in the study have excellent monitoring capabilities; the remaining cities have moderate; to limited capabilities. Measurement of PM and sulphur dioxide (SO_2) is the most widespread; the least measurements being made for lead (Pb), ozone (O_3), and carbon monoxide (CO). Active sampling techniques are the most widely used methodology, with continuous monitoring networks being increasingly introduced. Passive samplers are in very limited use in the cities participating in this study; this technique could provide useful additional information for characterising air quality at low cost.
- Most cities in this study carry out routine calibration and flow checks to ensure the accuracy of their monitoring data; less cities formally validate their results and very few have established formal data quality objectives, or conduct technical reviews or site audits. For many developing cities it is, therefore, difficult to determine the quality of monitoring data and whether it is adequate for its intended purpose.
- Assessments carried out on monitoring data were generally limited to simple statistics, percentiles, trends, and exceedances of air quality standards. Few cities use air quality monitoring data in combination with health indicators in epidemiological studies, or use meteorological and emissions data in dispersion models or to produce forecasts of pollution episodes. In general, cities do not make optimum use of their air quality data.
- Access to air quality information in most developing cities is available through published annual summary reports, although the numbers printed are sometimes limited and, consequently, the documents may not be widely distributed. Air quality information is available through the media in over half of the participating developing cities and, in a number of these, qualitative descriptions are used to assist non-experts in understanding. Additional emissions controls during periods of poor air quality have been introduced in very few of the cities.
- Estimation of emissions is generally the most limited component of management capability; twelve of the cities participating in this study have calculated emissions estimates but few are validated and most do not include non-combustion sources. In most developing cities which have constructed emissions estimates these must therefore be considered, particularly for some pollutants, only rough approximations and of unknown quality.

4. Emissions control approaches for developing cities

4.1 Command and control

Laws and regulations are at the heart of air quality management strategies. The traditional approach for developing and implementing air quality management strategies has been the "command and control" approach. This approach has several major features centred around the regulation of emissions. The command and control approach usually involves:

- The development and regulation in law of emissions standards;
- The licensing of emissions sources;
- The monitoring and reporting of emissions;
- Penalties for exceeding license conditions.

Under this system, the techniques to be used in areas such as pollution control are prescribed by government and compliance with conditions is checked by government inspectors. The government issues licences, sets emission standards, and checks compliance with standards. Non-compliance cases commonly go to court, which considers mitigating circumstances and sets penalties. New developments or major changes to sources are usually subject to environmental impact assessment, and new sources may be subject to tighter performance standards than existing operations.

The strengths of the "command and control" approach include:

- Public confidence;
- Juridical certainty to industry and the public;
- Establish a minimum condition;
- In some situations the command and control approach has worked extremely well, and many countries have reduced emissions of SO_2, coarse particles and reduced or eliminated lead emissions from petrol.

The weaknesses of the approach include:

- Time-consuming, expensive, and legalistic procedures;
- Imposed light penalties unsatisfactory for all involved;
- Rigid approach, with the potential for arbitrary decisions and a focus on end-of-pipe solutions, instead of more comprehensive pollution prevention approaches;
- No provision of incentives to minimise emissions;
- Ignoring equity, often requiring highly expensive best-available technology for new sources, while existing sources with a lower level of technology and performance continue to pollute.

In spite of its weaknesses, the "command and control" approach is the most widely used technique around the world, both in developing and developed countries.

In recent years, the trend in most developed countries has been towards decreased use of the command and control approach, and increased use of other forms of regulatory control—economic instruments, co-regulation, and self-regulation (see Table 9). In the approach of self-regulation it is argued that some industry groups are familiar with current best practice within their own industry. Therefore, they can set codes of practice, industry standards, and targets, including self-monitoring of compliance, and may be subjected to audits. However, self-regulation measures may inspire less public confidence than regulatory control by government.

The use of economic instruments decreases the operating costs for pollution prevention by *e.g.* reducing subsidies for energy use; and subsidising zero emissions products (UNECE 1999). Pricing policies are a powerful economic instrument for air quality improvements. Another market-oriented approach is a system of tradable emission permits. In this system, the regulating authority quantifies the total mass of emissions permitted in an area and issues an equivalent number of tradable emissions entitlements. These tradable permits can be freely bought and sold. A typical example of this approach is the RECLAIM (REgional Clean Air Incentives Market) programme of California. Under this programme, hundreds of polluting facilities are required to cut their emissions of nitrogen (NO_X) and sulphur oxides (SO_X). It was expected that between 1994 and 2003 NO_X would be reduced by 70%; however, this goal was by far not achieved due to the setting of too general caps for NO_X emissions (US EPA, 2002; 2006).

Companies and their industry organisations have been included in discussions of options for regulation reform, and in the review of these

Table 9: 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 Government audits Emission standards
Economic instruments	Use of pricing, subsidies, taxes, and charges to alter production and consumption patterns of organisations and the public	Load-based emission charges Tradeable emission permits Differential taxes True cost pricing of resources
Co-regulation	Formulation and adoption of rules, regulations and guidelines in consultation with stakeholders, negotiated within prescribed boundaries	National registers of pollution emission inventories
Self-regulation	Self-imposition of regulations and guidelines and environmental audits by industry groups. Voluntary adoption of environmental management measures	Voluntary codes of practice Self-audit Emission reduction targets Environmental management systems

Source: After Bradfield *et al.*, (1996)

options. This pro-active approach by industry organisations has led to a degree of co-regulation in some areas. It has resulted in the adoption of regulations and guidelines considered to be practical and realistic by stakeholders, and have simplified and reduced the costs of compliance for national governments.

Self regulation is based on a growing worldwide adoption of environmental management systems. These include the British Standard 7750, the European Union Eco-Management and Audit Scheme (EMAS), and the environmental management system of the International Organisation for Standardisation, the ISO 14000 series (ISO 1996a; b; Sheldon 1997). The adoption of environmental management systems has also influenced the process by which governments define industrial emissions outcomes, while not prescribing to industry how these outcomes should be achieved. The EMAS is a management tool for all economic sectors including public and private services to report and improve their environmental performance (EU, 2001; 2008b). More details of economic instruments, co-regulation and self regulation are discussed in WHO 2000, SEI 2008 and in *Sourcebook* Module 1d: *Economic Instruments*.

Emissions control options should involve broad strategic approaches, such as land use, transportation, energy, and industrial development planning. Unless air quality planning has a consistency with these other areas, substantial progress is difficult. Complex models have been developed to assess the interaction and consequences of changes in these areas for air quality. However, changes in land use, transportation, energy, and industrial development planning may take decades to substantially improve air quality, so more specific tactics to control emissions are needed. A decision support system for industrial air pollution control is available which aims to support policy makers and managers in analysing and formulating policy options and control measures (WHO 1995b). The SEI Foundation Course for Air Quality Management has developed a special module which addresses many of these questions (SEI 2008). A World Bank report entitled "Low Cost Solutions to Achieve Better Air Quality in Sub-Saharan African Cities" was published recently summarizing low cost options for AQM components (emissions, modelling, monitoring, health and environmental impact assessment) and for policies in the transport and industry sectors and for pollution from area sources, transboundary dispersion and greenhouse gas emissions.

4.2 Evaluation of control options

Unless legal constraints prescribe a particular control option, the evaluation of control options must take into account the following factors:

- Technical practicability;
- Financial viability;
- Social equity of costs and benefits;
- Costs and benefits for health and environment;

- Speed with which control options can be implemented;
- Enforceability.

Although large improvements in air quality have been achieved in some developed countries, the financial costs have been high, and the resource demands of some approaches make them unsuitable for poorer developing countries.

Some countries determine air pollution control requirements on the basis of an assessment of the effects of the pollutants on health and the environment (effect-oriented). Increased emissions may be permitted where the assessment suggests there will be no health or environmental impacts, or ambient air quality standards will not be exceeded. Action may be taken to reduce outdoor concentrations where impacts or exceedances are shown to occur. Other countries base their air quality management policies on the requirement for best available technology, or best available techniques not entailing excessive cost (source-oriented). Most developed countries apply a combination of both source-oriented and effect-oriented principles (UNECE 1999).

4.3 Control of point sources

Air quality management options at point sources refer to:

- Siting and planning;
- Source emissions reduction;
  - Management and operational changes;
  - Process optimisation;
  - Combustion modifications;
  - Fuel modifications;
- Emissions control.

The most powerful and cost-effective air quality management options occur during the planning stages of a new facility. Planning options involve careful site selection, to maximise dispersion, and location of the proposed facility away from sensitive receptors, such as residential areas or areas of natural or commercial sensitivity.

Options involving changes in existing production processes or pollution control technology are more limited in scope. Cost-effective approaches to controlling existing air pollution sources are those that entail source emissions reduction: management and operational changes; process optimization; combustion modifications; and fuel modifications. Each approach has a different level of effectiveness on the various air pollutants. For example, process optimization may considerably reduce emissions of volatile and hazardous compounds, but can have little effect on NO_X and SO_2 emissions. In contrast, fuel modifications can decrease NO_X and SO_2 emissions but they may have little effect on volatile and hazardous compounds.

Management audits of emissions, sources, and source strength, and subsequent changes in operation require the implementation of good practices in housekeeping and maintenance, to ensure that systems are in place to check that equipment is maintained, and that staff are trained and properly supervised. It aims to minimize fugitive emissions, and losses from stored liquids and solids, by changing the composition of materials used, provided this can reduce emissions while maintaining product quality.

Process optimisation seeks to achieve emissions reductions by altering the production process without loss of product quality or production volume. It usually involves conducting a series of changes in which a factor involved in the manufacturing process is altered, such as temperature, ventilation or line speed.

Changes to the way in which combustion occurs, increasing the fuel flow in burners, changes in the geometry of the combustion chamber, and tight control over the oxygen feed into the burner can substantially reduce emissions of NO_X.

"The most powerful and cost-effective air quality management options occur during the planning stages of a new facility."

The simplest approach to fuel modification is to change the fuel from a relatively dirty fuel, such as coal, to a cleaner fuel such as natural gas. This is usually a cheaper means of reducing emissions than scrubbing SO_2 from emissions. Blending of fuels is also used, such as the blending of low-sulfur coal with high-sulfur coal, and coal/oil blends to reduce emissions of SO_2. Emissions from processes using coal as a fuel can also be reduced by coal washing, which reduces the proportion of contaminants in coal.

Tall stacks have traditionally been used to reduce ground-level concentrations of air pollutants at minimum cost to the producer. Their effectiveness depends on height, the velocity, and temperature of the stack gases, and atmospheric conditions such as wind speed and direction, atmospheric stability, local topography and air quality. Stacks of 200–400 metres in height are reasonably effective at reducing ground-levels concentrations of air pollutants when they are suitably sited. However, tall stacks do not reduce emissions. They distribute them over a wide area. Where the magnitude of emissions within a region is substantial, or the receiving environment is sensitive, serious environmental effects such as acid deposition and forest decline can occur in remote locations.

There are several techniques to control particle and gaseous emissions (described in detail in the standards literature; *e.g.* Liu and Liptak 1997). While these control techniques can be very effective, some are expensive in capital and maintenance infrastructure, and may be beyond the resources of some developed and developing countries. However, not all approaches need be expensive. Source reduction techniques are often the most cost-effective and suitable measures for many developing countries. These include fuel modifications, such as the preparation and use of low-sulfur and low-ash fuels, combined with management and operational approaches to reducing emissions.

4.4 Control of mobile sources

4.4.1 Situation analysis

In city centres, vehicles may be responsible for 90–95% of CO and Pb and lead and 60–70% of NO_X and HC. As vehicle emissions usually occur near to the breathing zone of people, exposures can be high and they can represent substantial health risks.

While most of the vehicle population is in developed countries, motor vehicle pollution in developing countries is rapidly worsening due to increasing vehicle fleet growth (Figure 12), increasing distances travelled, and high rates of emissions from the vehicle fleets. The causes of the high emissions rates include high proportions of polluting two-stroke engine vehicles, road congestion which increases emissions per kilometre travelled, poor fuel quality including high lead content, inadequate emissions controls, poor maintenance, and high average age of the vehicle fleet (see the factors listed in Box 8).

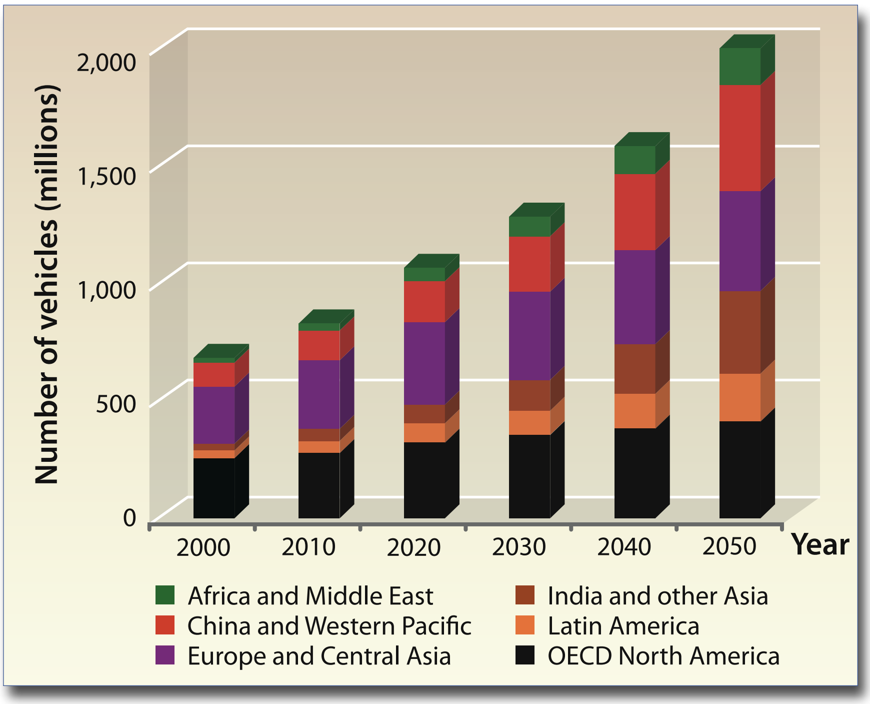


Figure 12
Growth of light duty vehicle population for several world regions.
Source: M. Walsh, private communication

Many countries have acted to regulate and enforce emissions reductions, so ambient concentrations of vehicle-related air pollutants—NO_X, CO, lead, and hydrocarbons—have declined in most developed countries over the last two decades (USEPA 1995; UNECE 1999). Although in the most wealthy of the developing countries significant improvements in air quality are occurring, in most other developing countries for which data are available, both vehicle emissions and ambient concentrations of vehicle-related air pollutants have increased (WHO 1997). All countries, however, which phased out lead as an additive to increase the antiknock behaviour of gasoline have observed a significant decline in airborne lead concentrations. This latter successes base on the consideration of emissions reduction at the most relevant source, which was then considered to be the source the manipulation of which would be most cost-effective. Such a success constitutes an incentive to focus future measures on the heavy polluters in developing cities, which presently mean diesel vehicles in practice. The reduction of sulphate emissions from diesel vehicles would, therefore, be the next

Box 8: Factors influencing motor vehicle emissions

A range of factors influence emission of pollutants from mobile sources including, for example:

Vehicle/fuel characteristics

- Engine type and technology; fuel injection, type of transmission system, other engine features;
- Exhaust, crankcase, catalytic converters, exhaust gas recirculation;
- Age, mileage, engine mechanical condition and adequacy of maintenance;
- Fuel properties and quality (see generally the *Sourcebook* modules on *vehicles and fuels*).

Fleet characteristics

- Vehicle mix (number and type of vehicles in use);
- Vehicle utilization (kilometres per vehicle per year) by vehicle type;
- Age profile of the vehicle fleet;
- Emission standards in effect and incentives/disincentives for purchase of cleaner vehicles;
- Adequacy and coverage of fleet maintenance programs;
- Clean fuels programs.

In developing cities, small numbers of the vehicle fleet ('high-emitters') often contributing high proportions of contaminants.

Operating characteristics

- Altitude, temperature, humidity (for NO_X);
- Vehicle use patterns—number and length of trips, number of cold starts, speed, loading, aggressiveness of driving behaviour;
- Degree of traffic congestion, capacity and quality of road infrastructure, and traffic control systems;
- Transport demand management programs.

Box 9: Air Quality Management in Santiago de Chile

In 1998, Santiago de Chile adopted a comprehensive air quality management plan (Plan de Prevención y Descontaminación Atmosférica) under the aegis of Santiago's competent environmental authority CONEMA and with the involvement of 17 institutions from 9 ministries. In addition to its purely technical mechanisms, the plan also includes some distinctly market-oriented instruments. Rapid urbanisation coupled with particularly high rates of industrialisation and expanding traffic volumes since the 1980s made it necessary to take drastic steps to counter the resultant intolerable transgressions of air quality standards for dust, respirable particles, carbon monoxide and ozone.

The plan is based on six principles:

- The participation of social groups in the design and implementation of the measures;
- Prevention;
- Polluter responsibility;
- The "polluter pays principle" (principle of causation);
- The (cost) effectiveness of measures; and
- The gradual implementation of measures to allow their gradual adaptation.

The defined measures, exceeding 100 in number, apply to the transport, industrial, construction and agricultural sectors. In addition to establishing and monitoring emission standards for industrial activities and transportation and regulations governing the reduction of suspended particulate emissions, the plan also relies on market-economy instruments. New industrial undertakings, for example, are now required to purchase emission rights corresponding to 120% of the factory's own emissions (overcompensation). Also, tax and rate-to-pay incentives have been created with a view to internalising external effects; *e.g.* via specific fuel levies.

The plan's ambitious goal is to reduce, by the year 2011, most harmful emissions to roughly 50% of their 1997 levels; despite further anticipated economic development. The implementation of the plan is subject to regular monitoring, and periodical updating of the plan (beginning in the year 2000) is envisaged.

GTZ has been making important contributions to Chile's past efforts to control air pollution and to elaborate the plan. The last phase of the project focused on the provision of advisory services for coordinating the implementation of the air quality control plan, the public relations work and community participation, the integration of urban development and mobility planning, and the further improvement of the monitoring systems for stationary and mobile emission sources, including the definition of standards. In the course of project implementation, public private partnerships, technology transfer and regional city-to-city cooperation in Latin America gained significance as major thematic areas.

GTZ, Oct. 2002

Table 10: Phasing out of lead in Asia and Africa

Year	Country in Asia	Country in Africa
1999	Japan; Malaysia; Republic of Korea; Singapore; Thailand	
2000	China Taiwan; India; Maldives;	
2001	Bangladesh; China; Philippines; Samoa; Vietnam	
2002		
2003	Brunei Darussalam; Pakistan; Sri Lanka	Nigeria; Mauritius; Sudan
2004	Papua New Guinea	Benin; Cameroon; Central African Republic; Chad; Eritrea; Ethiopia; Ghana; Mauritania; Niger
2005		Angola; Burkina Faso; Burundi; Côte d'Ivoire; Equatorial Guinea; Kenya; Liberia; Madagascar; Malawi; Mali; Mozambique; Sao Tome and Principe; Senegal; Tanzania; The Gambia; Togo; Uganda
2006	Fiji; Indonesia; Kitibati; Marshall Islands; Palau; Solomon Islands; Tonga; Tuvalu; Vanuatu	Botswana; Djibouti; Guinea; Lesotho; Namibia; Rwanda; Sierra Leone; Somalia; South Africa; Swaziland; Zimbabwe
2007	Cambodia;	Zambia
2008	Lao People's Democratic Republic; Mongolia; Timor Leste	
2009		
	Democratic People's Republic of Korea; Myanmar	Comoros; Gabon; Réunion; Seychelles; Sierra Leone

Source: PCFV (2009)

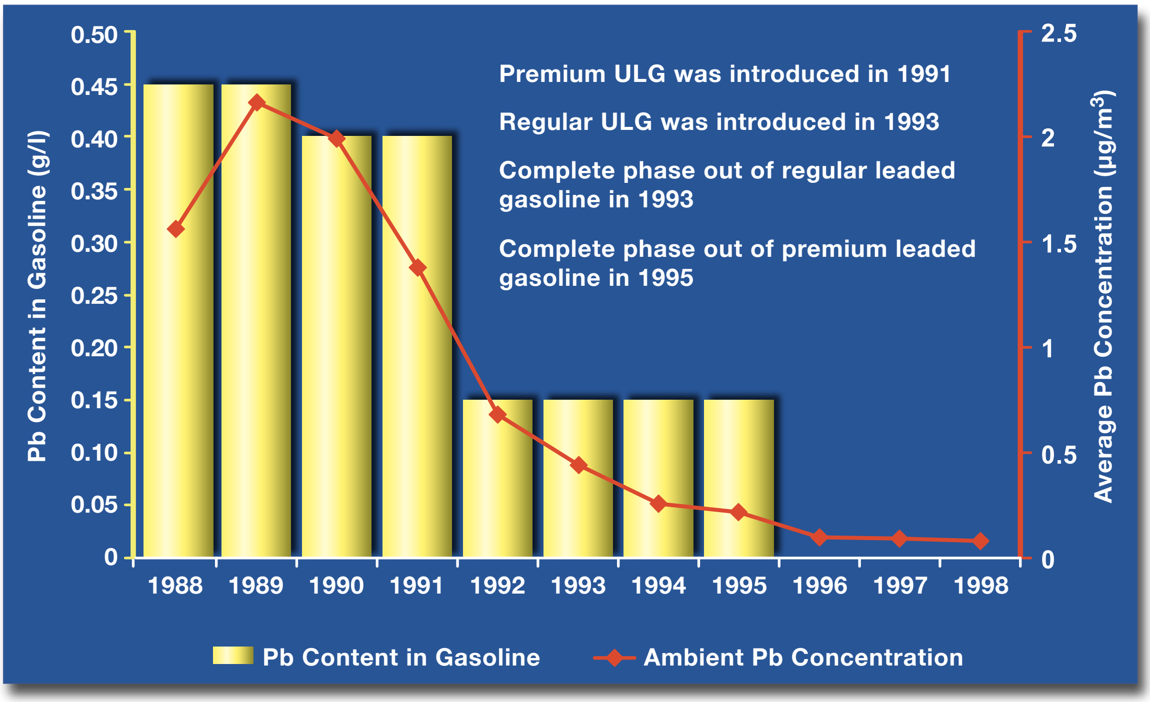


Fig. 13
Ambient lead (Pb) concentrations in Bangkok and Pb in gasoline, 1988–1998.
Supat, ADB Clean Fuels Workshop, New Delhi, May 2001

cost-effective step forward, to reduce particulate matter concentrations and corresponding health effects in developing cities.

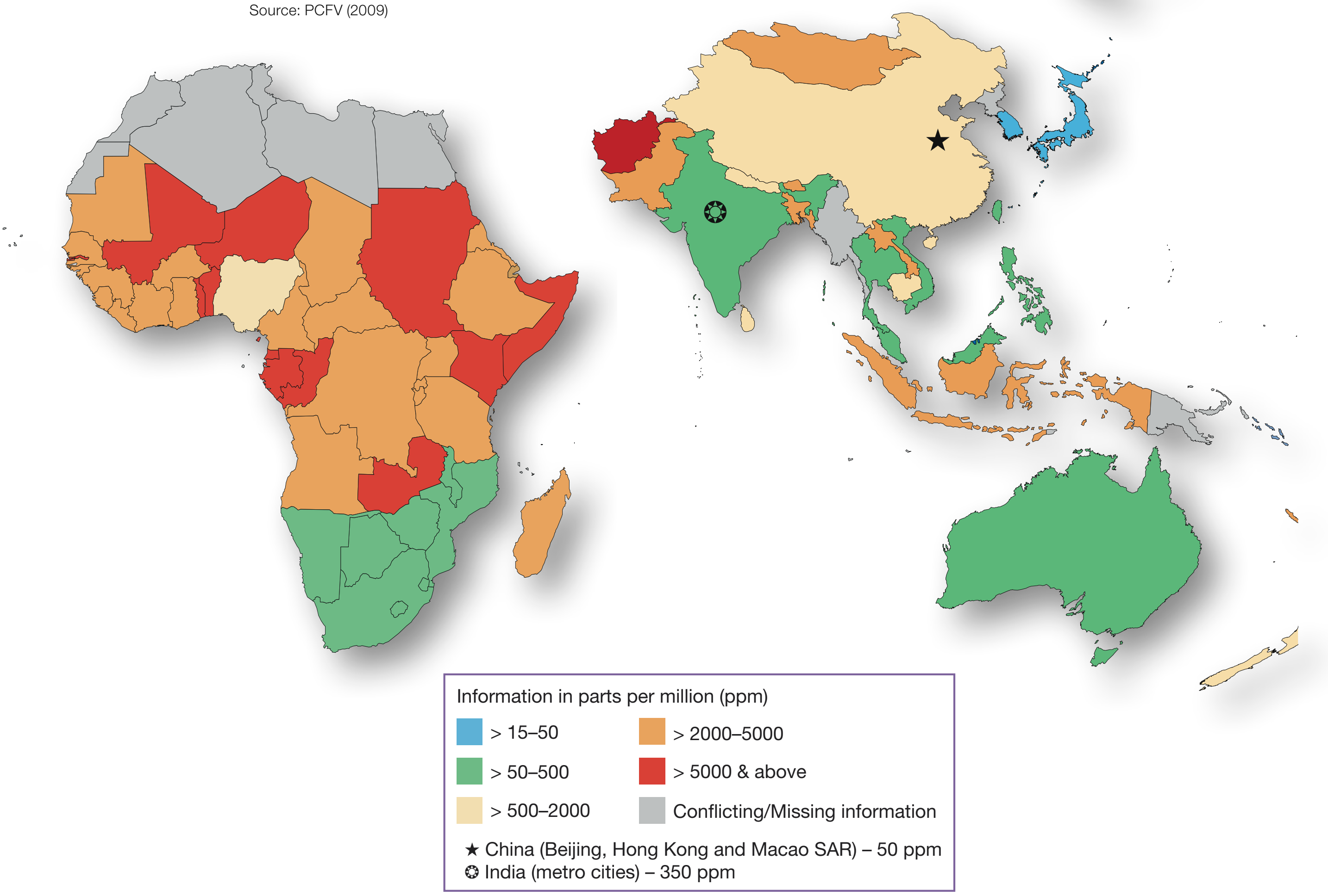
Legislation to lower or remove lead additives from gasoline has been implemented or will soon be implemented in many developing countries. This strategy can be very successful in immediately reducing atmospheric concentrations of lead. Table 10 shows the timelines of the phasing out of leaded gasoline in Asia and Africa.

Figure 13 shows the correlation between leaded gasoline and levels of lead in the ambient air in Bangkok, showing that rapid reductions in ambient lead levels are possible with the phasing out of lead in gasoline. Figures 14a–c show the current sulphur content of diesel in Africa, Asia and Latin America (PCFV, 2009).

Figure 14a-c

Sulphur content in diesel by country.

Source: PCFV (2009)



4.4.2 Control

The main components of an integrated air quality management strategy for a developing city will generally include:

- Cleaner vehicle and fuel technologies;
- Traffic management, and economic and financial measures to discourage the use of private cars and motorcycles and to encourage the use of public transport and non-motorised transport modes;
- Public transport improvements;
- Institutional and policy-oriented reforms, and public participation.

Leading examples of such integrated AQM strategies are Mexico City and Santiago de Chile (see Box 9).

An overview of opportunities in reducing emissions from individual vehicles, and test cases that examine the effects and potential benefits of technical options for reducing vehicle emissions is presented in *Sourcebook* Module 4a: *Cleaner Fuels and Vehicle Technologies.*

Vehicle emission standards, now in effect in all industrialised countries, have also been adopted in many developing countries. Table 11 shows implementation dates for emission standards for new vehicles in Asia (CAI-Asia, 2009).

Improving fuel quality will immediately reduce emissions from all fuel burning equipment without the installation of any additional equipment or change in utilisation.

In the longer term it is also possible to change the pattern of urban development to reduce the amount of travel and therefore the amount of fuel being used and emissions produced.

As identified, the most effective air quality management strategies should use a range of emissions control strategies to achieve acceptable air quality as defined by an air quality standard.

The experience with vehicle inspection programs (see *Sourcebook* Module 4b: *Inspection & Maintenance and Roadworthiness*) in developing countries has often been poor (an anecdotal reason for that may be inferred from Figure 15), and the use of sophisticated vehicle control technologies is expected to have greatest utility in only the more advanced of the developing countries. The most promising approaches for controlling vehicle emissions in developing countries are likely to be through policies to promote greater

Table 11: Implementation timelines of emission standards for vehicles in Asia

Country	95	96	97	98	99	2000	01	02	03	04	05	06	07	08	09	10
European Union	Euro 1	Euro 2	Euro 2	Euro 2	Euro 2	Euro 2	Euro 3	Euro 3	Euro 3	Euro 3	Euro 4	Euro 4	Euro 4	Euro 5	Euro 5	Euro 5
Bangladesh[a]											Euro 2	Euro 2	Euro 2	Euro 2	Euro 2	Euro 2
Bangladesh[b]											Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1
Hong Kong, China	Euro 1	Euro 1	Euro 2	Euro 2	Euro 2	Euro 2	Euro 3	Euro 3	Euro 3	Euro 3	Euro 3	Euro 4	Euro 4	Euro 4	Euro 5 (under discussion)	Euro 5 (under discussion)
India[c]							Euro 1	Euro 1	Euro 1	Euro 1	Euro 2	Euro 2	Euro 2	Euro 2	Euro 2	Euro 3
India[d]					Euro 1	Euro 2	Euro 2	Euro 2	Euro 2	Euro 2	Euro 3	Euro 3	Euro 3	Euro 3	Euro 3	Euro 4
Indonesia											Euro 2	Euro 2	Euro 2	Euro 2	Euro 2	Euro 2
Malaysia			Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 2 (under discussion)	Euro 2 (under discussion)
Nepal						Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1
Pakistan	No conclusive information available															
Philippines									Euro 1	Euro 1	Euro 1	Euro 1	Euro 2	Euro 2	Euro 2	Euro 2
PRC[a]							Euro 1	Euro 1	Euro 1	Euro 2	Euro 2	Euro 2	Euro 3	Euro 3	Euro 3	Euro 4
PRC[e]							Euro 1	Euro 1	Euro 2	Euro 2	Euro 2	Euro 3	Euro 3	Euro 4: Beijing only	Euro 4: Beijing only	Euro 4: Beijing only
Singapore[a]	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 2	Euro 2	Euro 2	Euro 2	Euro 2	Euro 2	Euro 2	Euro 2	Euro 2	Euro 2
Singapore[b]	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 2	Euro 2	Euro 2	Euro 2	Euro 2	Euro 4	Euro 4	Euro 4	Euro 4	Euro 4
Sri Lanka									Euro 1	Euro 1	Euro 1	Euro 1	Euro 2 (under discussion)	Euro 2 (under discussion)	Euro 2 (under discussion)	Euro 2 (under discussion)
Thailand	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 1	Euro 2	Euro 2	Euro 2	Euro 3	Euro 3	Euro 3	Euro 3	Euro 3	Euro 3	Euro 3
Viet Nam													Euro 2	Euro 2	Euro 2	Euro 2

(a) gasoline (b) Diesel (c) Entire country (d) Delhi, Chennai, Mumbai, Kolkata, Bangalore, Hydrabad, Agra, Surat, Pune, Kanpur, Ahmedabad, Sholapur, Lucknow; Other cities in India are in Euro 2
(e) Beijing and Guangzhou have adopted Euro 3 standards in Sept 2006 and Shanghai end of 2008 (f) Euro 2 was not mandated but Euro 2 fuel available at pump stations
(g) Equivalent to Euro 4 emissions standards

Euro 1 | Euro 2 | Euro 3 | Euro 4 | Euro 5 | under discussion

Source: CAI-Asia (2009)

use of transit, walking, and cycling, and restrict the growth of private automobile use. The strengthening of traffic management programs, improvements in public transport, restrictions on motorised traffic and encouragement of the use of cleaner-fuelled vehicles in fleets are also cost-effective means of reducing vehicle emissions, as set out in the various modules of this *Sourcebook*.

> ***"Policy measures to control vehicle ownership and use, and to encourage other forms of transport, are also commonly employed to support vehicle emissions programs."***

Most developed countries apply regulations for vehicle emissions as part of an international process under which vehicles and their component parts are required to be approved before marketing. Some countries also require regular in-service inspection and maintenance for emissions and safety, as a condition for continued operation of vehicles. This includes retrofitting or scrapping of non-conforming vehicles. Technology requirements for new vehicles in most developed countries include three-way catalytic converters, with closed loop and charcoal canister for petrol-fuelled passenger cars. There are also requirements that apply to diesel, light- and heavy-duty trucks and buses. Conventional two-stroke motorcycles are sometimes banned. There are programs to control fuel losses during refuelling. Virtually all developed countries now require use of unleaded fuels for new cars, and encourage their use by economic instruments.

Policy measures to control vehicle ownership and use, and to encourage other forms of transport, are also commonly employed to support vehicle emissions programs. For example, tight control over vehicle ownership and use in Singapore, especially within the central business district during the day, has contributed to reducing air pollution from motor vehicles (see *Sourcebook* Module 1d: *Economic Instruments*). Faced with dire air pollution problems, some Latin American cities have introduced programs such as no-drive days as a last resort on days when air pollution reaches extreme levels. More socially acceptable measures include incentives to develop and use public transportation, such as buses, light rail, and bicycles. Land-use planning approaches that encourage public transport and provide disincentives for use of private vehicles are attractive and cost-effective long-term measures (see *Sourcebook* Module 2a: *Land Use Planning and Urban Transport*).

Figure 15
Can you see the reading?

4.5 Control of area sources

The control of area sources of air pollutants involves a number of strategies, as the characteristics of area sources are highly variable. The options for controlling area sources can be classified as technical, regulatory, educational and market-based strategies (see Table 12).

Table 12: Strategies for controlling area sources

Strategy	Description
Technical	■ Search alternatives to existing polluting activities ■ Implement cleaner production, pollution prevention and ■ Best practices
Regulatory	■ Banning of emissions, banning of open burning, penalties, control of fuel quality
Educational	■ Informing the public about emissions, pollution impacts, poor quality fuels
Market-based	■ Polluter pays , incentives for using clean fuels, facilitate emission licenses for adopting best practices, true cost pricing of resources

5. Education and communication

Effective education and communication are important tools in raising public awareness of air quality issues. The successes of air quality management strategies have often involved action at all levels in the community. In many cases, central government action is triggered by local complaints from citizens. Actions to control air pollution have sometimes been possible only by establishing communications between local communities, local government and the national government agency responsible for air quality issues. Two-way communication between local communities and those responsible for air quality management is essential, and it requires use of many techniques to be successful.

"The successes of air quality management strategies have often involved action at all levels in the community."

Reporting air quality information in a form that is generally understandable by the public is a difficult problem. One approach is the use of the pollutant standard index. This system enables a wide range of air quality components, concentrations, and averaging times to be reported to the public as one simple normalised figure. Although a pollution index provides a relatively simple and easy way to disseminate information on the level of air pollution, there are difficulties associated with the setting of these indices. Most of these difficulties arise from the fact that the composition of the pollutant mixture varies in both time and space, and that the components of the mixture have different health impacts.

For a set of tools and approaches for raising public awareness and other means of education and communication campaigns, please refer to *Sourcebook* Module 1e: *Raising Public Awareness about Sustainable Urban Transport*.

6. Priority setting in AQM

6.1 Introduction

Priority setting in air quality management will differ for each city because a city or country sets priorities in air quality management according to its policy objectives, needs, and capabilities. Priority setting in air quality management refers to prioritising the health risks of air pollution, with corresponding prioritisation of the pollutants, and concentrating on the most important sources of the pollutants. High priority health risks will be given to those compounds for which "high" toxicity and "high" exposure of the population are entailed. Conversely, low priority health risks involve agents of "low" toxicity and "low" exposure. "Medium" priority risks include compounds for which toxicity is "low" and exposure is "high," or vice versa. Basic elements of the estimation and prioritisation of health risks comprises four steps: hazard identification, exposure assessment, exposure-response analysis, and risk characterisation (see Figure 15) (Younes *et al*., 1998; WHO 2000a).

In order to ensure a basis for decisions on risk-reducing measures and strategies for air quality management, including a consistent and transparent derivation of air quality standards, a framework for a political, regulatory and administrative approach is required. In such a framework the following considerations need to be included:

- Legal aspects;
- The potential of air pollution to cause adverse health effects in populations at risk;
- Exposure-response relationships of pollutants and pollutant mixtures and the actual exposure responsible for related health and/or environmental risks;
- The acceptability of risk;
- Cost-benefit considerations;
- Stakeholder contribution in setting standards.

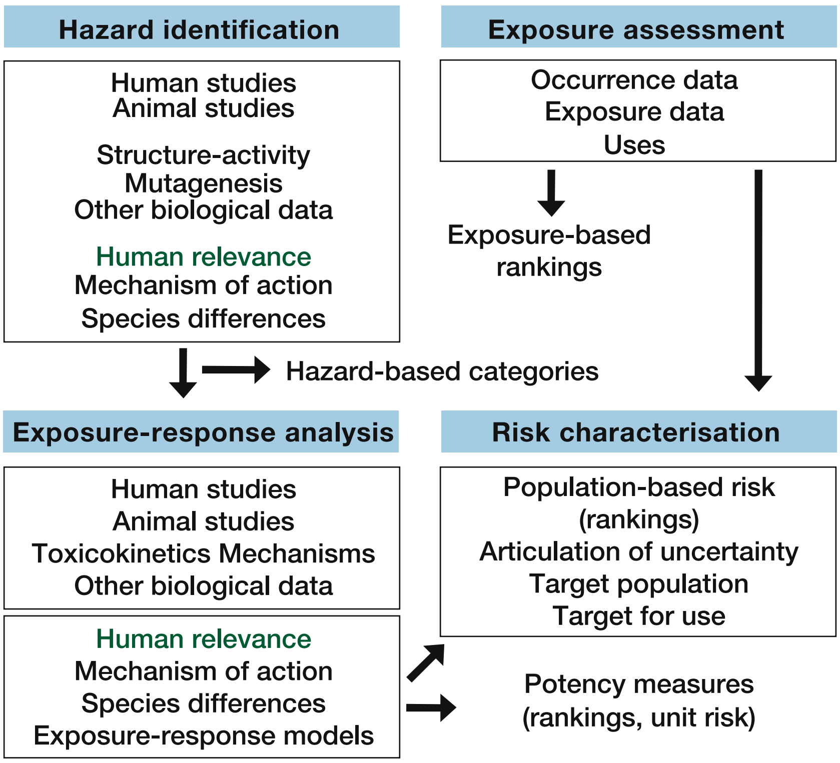
These issues are discussed in the following sections.

6.2 Legal aspects

A legislative framework usually provides the basis for policies in the decision-making process of setting air quality standards at the municipal, regional, national or supranational level. The setting of standards strongly depends on the risk management strategy adopted which, in turn, is influenced by country-specific socio-political and economic considerations and/or international agreements. Legislation and air quality standards vary from country to country, but in general, the WHO *Guidelines for Air Quality* (WHO 2000a; 2006) can provide guidance on how to consider the following issues in developing countries:

- ***Identification of the pollutants to be considered***—Provided the types of sources are known, the guidelines, and rapid assessment procedures of AMIS can identify the most important sources and estimate their emissions.
- ***Existing background concentrations of air pollutants***—The knowledge on global concentrations from national databases on air pollutant concentrations and the WMO Global Atmospheric Watch (WMO, 2007) can serve to estimate background concentrations of both air pollutants and greenhouse gases. The Decision Support System for Industrial Pollution Control (DSS IPC) and the GAPF emissions inventory are useful and user-friendly instruments to estimate concentrations on the basis of initial emissions estimates and simple dispersion models (WHO 1995b; GAPF 2008).

Figure 16
Basic elements of the estimation and prioritisation of health risks.



- ***Applicable monitoring methodology and its quality assurance***—The most appropriate and least-cost means for ground-based monitoring can be selected on the basis of the AMIS-GEMS/AIR Methodology Handbook Review Series (UNEP/WHO 1994a; b; c; d; Schwela 2003). In these publications UNEP and WHO give simple advice on monitoring, siting, and quality assurance when existing information and means are minimal. Publications from other agencies also provide insight into monitoring strategies (BMU 1997; AEA 1996; WHO/PAHO 1997; WHO/SEARO 1996).
- ***The numerical value of the standards for the various pollutants or the decision-making process***—Air quality standards may be based on WHO air quality guidelines, but other aspects, such as technological feasibility, costs of compliance, prevailing exposure levels, social, economic cultural conditions, are also relevant to the standard setting procedure and the design of appropriate emission abatement measures. Several air quality standards may be set, *e.g.* effect-oriented standards as a long-term goal and less stringent standards to be achieved within shorter time intervals. As a consequence, air quality standards differ widely from country to country (WHO 1998). The *Guidelines for Air Quality* enable country-specific air quality standards to be derived based on existing or estimated concentrations. The European Union and Switzerland have adopted most of the WHO guidelines as standards.
- ***Emission control measures and emission standards***—Given the types of sources and estimations of their emissions via the rapid assessment method and their spatial distribution, the DSS IPC and the GAPF emissions inventory can serve to simulate the efficiency of control measures and help to set appropriate emission standards for the main sources (WHO 1993a;b; WHO/PAHO/WB 1995; GAPF 2008).
- ***Identification and selection of adverse effects on public health and the environment to be avoided***—Health effects range from death and acute illness through chronic and lingering diseases, minor and temporary ailments, to temporary physiological

or psychological changes. Standards should be based on adverse effects of air pollutants. Consideration of health effects that are either temporary or reversible, or involve biochemical or functional changes with uncertain clinical significance, need not be considered in the first step of deriving a standard in developing countries. Judgements as to adversity of health effects may differ between countries because of, for example, different cultural backgrounds and different levels of health status. Air quality standards strongly influence the implementation of air pollution control policies. In many countries, the exceeding of standards is linked to an obligation to develop action plans at the municipal, regional or national level to abate air pollution (clean air implementation plans).

- ***Identification of the population to be protected from adverse effects on health*** – The most sensitive subgroups of the population include infants, pregnant women, disabled persons, and the elderly. Other groups may be judged to be at higher risk due to enhanced exposure (outdoor workers, athletes, and children). The sensitive groups in a population may vary across countries due to differences in medical care, nutritional status, lifestyle, and/or prevailing genetic factors, or due to the existence of endemic diseases or the prevalence of debilitating diseases. The air quality guidelines have been set with respect to the sub-groups more sensitive to air pollution. Setting standards on the basis of the guidelines and considering the consequence of uncertainty provide at least some protection for these sub-populations.

6.3 Adverse effects on health

In setting air quality standards, it is usually decided to protect the population from adverse effects due to air pollution. The distinction between adverse and non-adverse effects, however, poses considerable difficulties (WHO 1987). Very often, the term "adverse health effect" is used in clean air acts and regulations without giving a definition. In 2000, an expert committee of the American Thoracic Society endeavoured to identify factors, which could help to define an adverse respiratory effect due to air pollution, although specific boundaries for separation adverse from non-adverse effects are not given (ATS 2000). According to the deliberations of the committee, adverse effects of air pollution at the population or individual level include:

- Any effect on mortality;
- Detectable effects on clinical measures;
- Any detectable level of permanent lung function loss;
- Decreased health-related quality of life;
- Reversible loss of lung function in combination with the presence of symptoms;
- A shift in the risk factor distribution, and hence the risk profile of the exposed population.

> *"Air quality standards strongly influence the implementation of air pollution control policies."*

The WHO defined adverse health effects in several publications (WHO 1978; 1994; WHO/EURO 1987). The most recent definition is:

> "An adverse effect is any change in morphology, physiology, growth, development or life span of an organism which results in impairment of functional capacity, or impairment of capacity to compensate for additional stress, or increase in susceptibility to the harmful effects of other environmental influences."

The WHO notes, however, that even this elaborate definition incorporates significant subjectivity and uncertainty in defining an adverse effect of air pollutants on health. More serious effects are generally accepted as adverse. But when the health effects are either temporary and reversible, or involve biochemical or functional changes with uncertain clinical significance, a judgement is required on whether these less serious effects should be considered when deriving air quality standards. Judgements as to whether the health effects are adverse may differ between countries, because of factors including different cultural backgrounds and different levels of health status. The use of biomarkers or other indicators of exposure may provide a basis for setting air quality standards. Changes in such indicators, while not necessarily being adverse effects in themselves, may be harbingers of adverse effects on health. An example is blood lead content as an indicator of likely impairment of neuro-behavioural development.

6.4 Population at risk

The population at risk is that part of the population that is exposed to enhanced concentrations of air pollution. Each population has sensitive groups or sub-populations that are at higher risk for developing health effects following exposure to air pollutants. Sensitive groups include individuals impaired by concurrent diseases or other physiological limitations, and those with specific characteristics, which makes them more vulnerable to air pollutants (*e.g.* infants, elderly people). Other groups may be judged to be at higher risk due to enhanced exposure (outdoor workers, athletes, children). The sensitive groups in a population may vary across countries due to differences in medical care, nutritional status, lifestyle, and/or prevailing genetic factors, or due to the existence of endemic diseases or the prevalence of debilitating diseases.

6.5 Exposure-response relationships

In general, there is limited information available on exposure-response relationships for inorganic and organic pollutants, especially at low exposures. The 2000 WHO *Guidelines for Air Quality* provided linear exposure-response relationships (together with their 95% confidence intervals) for particulate matter instead of guideline values. For PM_{10} and $PM_{2.5}$ the changes of various health endpoints such as daily mortality and hospital admissions with each 10 μg/m^3 increase in concentrations were quantified by these relationships (WHO 2000a).

The 2005 update of the guidelines for particulate matter and some gaseous compounds abandoned this approach and quoted again guideline values for PM_{10} and $PM_{2.5}$ and some interim guideline values in order to delineate a way for developing countries on how to achieve the guideline values in a stepwise procedure (WHO 2006). The guideline and interim target values are presented in Table 13 and compared to the historical values for PM_{10} between 1972 and 1987.

Table 13: WHO 2006 guideline values for particulate matter in outdoor air in perspective to WHO's historical guideline values

Source	Pollutant	Guideline value [μg/m^3]	Averaging time	Statistical meaning	Interim target 1 [μg/m^3]	Interim target 2 [μg/m^3]	Interim target 3 [μg/m^3]
WHO 2006	$PM_{2.5}$	25	24 hours	99-percentile	75	50	37.5
		10	1 year	annual mean	35	25	15
	PM_{10}	50	24 hours	99-percentile	150	100	75
		20	1 year	annual mean	70	50	30
WHO/ EURO 1987	Black smoke; in conjunction with sulphur dioxide	125	24 hours	Not stated			
		50	1 year	Arithmetic mean			
	TSP; in conjunction with sulphur dioxide	120	24 hours	Not stated			
	PM_{10}; in conjunction with sulphur dioxide	70	24 hours	Not stated			
WHO 1979	Black smoke; in conjunction with sulphur dioxide	100-150	24 hours	98-percentile			
		40-60	1 year	Arithmetic mean			
	TSP; in conjunction with sulphur dioxide	150-230	24 hours	98-percentile			
		60-90	1 year	Arithmetic mean			
WHO 1972	Black smoke; in conjunction with sulphur dioxide	120	24 hours	98-percentile			
		40	1 year	Arithmetic mean			

For carcinogenic compounds, the quantitative assessment of the unit risks provides an approximate estimate of responses at different concentrations. These relationships, which are extensively discussed in the *Guidelines for Air Quality (WHO 2000a)*, give guidance to decision-makers to determine the acceptable risk for the population exposure to particulate matter and to carcinogenic compounds and set the corresponding concentrations as standards.

6.6 Exposure characterisation

Exposure to air pollution is not only determined by ambient air pollutant concentrations. In deriving air quality standards that protect against the adverse health impacts, the size of the population at risk (*i.e.* exposed to enhanced air pollutant concentrations) is an important factor to consider. The total exposure of people also depends on the time people spend in the various environments: outdoor, indoor, work place, in-vehicle and other. Exposure also depends on the various routes of intake and absorption of pollutants in the human body: air, water, food and tobacco smoking. Therefore, it should be kept in mind that there is a weak relationship between pollutant concentrations and personal exposures. An example of this weak relationship is provided by indoor air pollution when biomass fuels are used for heating and cooking. However, in developing countries, ambient air concentrations are at present the only readily available surrogate for estimating personal exposures.

6.7 Risk assessment

Air quality guidelines and standards are based on health or ecological risk models. These models provide a tool that is increasingly used to inform policy-makers on some of the possible consequences of air pollutants at different pollutant levels which correspond to various options for standards. Using this information, the policy-maker is able to perform a regulatory risk assessment of air pollution induced effects. Regulatory risk assessment in air pollution management includes the following steps: hazard identification, development of exposure-response relationships, exposure analysis, and quantitative risk estimation.

The first step, ***hazard identification***—and, to some extent, the second step, ***exposure-response relationships***—have already been provided in the air quality guidelines. The third step, ***exposure analysis***, may predict changes in exposure associated with reductions in emissions from a specific source or group of sources under different control options. The final step in regulatory risk assessment, ***risk analysis***, refers to the quantitative estimation of the risk of health effects in the exposed population (*e.g.* the number of individuals who may be affected).

Regulatory risk assessments are likely to result in different risk estimates across countries and economic regions owing to differences in exposure patterns and in the size and characteristics of sensitive groups.

6.8 Acceptability of risk

In the absence of thresholds for the onset of health effects—as in the cases of fine and ultrafine particulate matter and carcinogenic compounds—the selection of an air quality standard that provides adequate protection of public health requires the regulators to determine an acceptable risk for their population. Acceptability of the risks, and therefore the standards selected, will depend on the expected incidence and severity of the potential effects, the size of the population at risk, and the degree of scientific uncertainty that the effects will occur at any given level of air pollution. For example, if a suspected but uncertain health effect is severe and the size of the population at risk is large, a more cautious approach would be appropriate than if the effect was less troubling or if the population was smaller.

The acceptability of risk may vary among countries because of differences in social norms, degree of risk aversion and perception in the general population and various stakeholders. Risk acceptability is also influenced by how the risks associated with air pollution compare with risks from other pollution sources or human activities.

6.9 Cost-benefit analysis

Cost benefit analysis is a tool to aid in decision-making regarding the impact of air pollution. Air pollution results in potentially serious health-related social costs in the form of

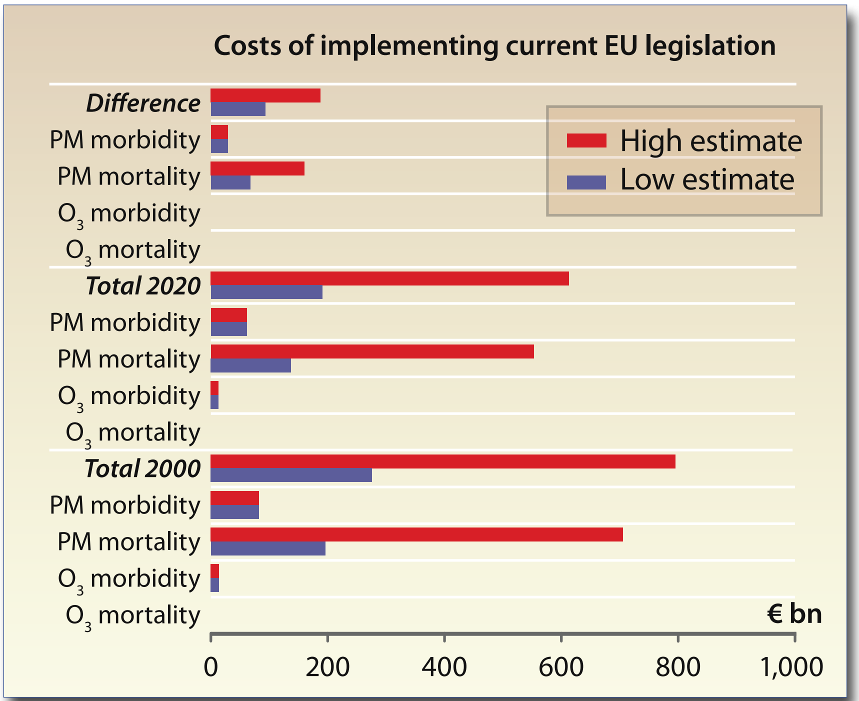


Figure 17
Comparison of the costs of CAFÉ AQM implementation 2000 and 2020.

illness (***morbidity***) or premature death (***mortality***). Such costs can be quantified through various approaches. An increasingly common approach—though as with other approaches not without problems—is the use of Willingness-to-pay surveys. By determining how much people are prepared to pay to avoid a particular level of risk, that extra risk (of death or illness) can be quantified in monetary terms. The economic valuation of health effects of air pollution must be factored into the cost benefit analysis of air pollution control mitigation measures.

Table 14: Comparison of gaseous emission reducing devices

MEASURE	
Application of 3 way converters	
Emission controlled	Tail pipe emissions (CO, VOC, NO_x and lead) of ignition powered vehicles (4-stroke gasoline)
Effectiveness	90% reduction of tailpipe emissions of CO, NO_x and VOC Must be used in conjunction with unleaded gasoline
Viability	Strict inspection & maintenance requirements, with a supply of unleaded gasoline. Catalyst can become contaminated through use of leaded or poor quality fuels.
Costs	For tailpipe catalyst and fuel control systems, up to US$400.
Application of catalytic converters (oxidation catalysts)	
Emission controlled	Tail pipe emissions (CO, VOC, NO_x and lead) of ignition powered vehicles (including some mixed fuel motors)
Effectiveness	90% reduction of tailpipe emissions of CO, NO_x and VOC Must be used in conjunction with unleaded gasoline
Viability	Strict maintenance and inspection requirements, together with a supply of unleaded gasoline. Catalyst can become contaminated through use of leaded or poor quality fuels. This technology requires fewer modification to vehicle engines.
Costs	About US$200 per vehicle

Adapted from World Bank, 1997

The input parameters for prediction of the costs associated with pollution are often only estimations, so monetary values attributed to air pollution costs are only approximations.

An overview of steps in the determination of environmental/damage assessment (Shah *et al.*, 1997) includes the following:

1. Identification of the population and assets at risk due to pollution, through the use of such tools as impact matrices.
2. Determination of the number of people or assets within the potential impact area. For example, those at risk may be all the residents of a polluted area. Residents living in close proximity to a major road bounded by an isohyet (a line joining places of equal value on a map) for PM_{10} in excess of the determined health standard could be considered at risk.
3. Identification of dose-response functions that relate ambient levels of pollution to impacts on human health or on assets. As impacts are related to the pollution concentrations, this often takes the form of a mathematical algorithm to describe dependant impacts.
4. Determination of the marginal physical impacts by multiplying the population at risk and/or the assets at risk by with the impact per unit of pollution from 3.
5. Determination of the monetary losses attributed to each of marginal physical impacts. As noted previously, a number of the physical costs can be directly equated to market prices (clean-up costs, loss of crops at the market value), but impacts on human health are much more difficult to equate.
6. Calculation of monetary value of benefits/damage due to the change in air pollution by multiplying figures derived in 4 by those in 5.

In the absence of measured or locally derived values for any of the above, approximate values can be determined from equivalent or similar studies elsewhere, and applied until more relevant values can be determined. Care must be taken when interpreting the outcomes of values determined on the basis of values determined from other cultures or socioeconomic groups. For example, dose-response estimates from the United States assume an average body mass of 70 kg for men. This is unreasonable in the context of consideration of impacts on countries where average weights may be significantly lower.

In the analysis of options we need to consider the costs and benefits of technical and policy measures to reduce emissions. Such an approach has recently been published by the EU for its Clean Air for Europe (CAFÉ) programme (AEAT 2005). This report presents the benefits analysis for the CAFE baseline and the EU Thematic Strategy. The analysis has used concentration data output by the RAINS model for PM health impact assessment, and pollution data from the EMEP model for other pollutants (including effects on ecosystems). It assesses the state of the environment in 2000 and 2020, and looks at the benefits of current policies over this period. Results are presented for the following receptors:

- Health (mortality and morbidity);
- Materials (buildings);
- Crops;
- Ecosystems (freshwater and terrestrial, including forests).

Where possible the analysis has been carried through to economic valuation, though this was not possible for ecosystems and for materials used in cultural heritage.

This report summarises the benefits baseline for air quality in Europe from 2000 to 2020. It reveals that large benefits are predicted to occur from current policies over this time, with quantified air pollution impacts falling by €89 billion to €183 billion per year as a result of current policies by 2020. Figure 17 illustrates these results.

The costs of pollution mitigation strategies need to be considered against the benefits to the community in the form of reduced death and illness, greater productivity, or related impacts. For example, Table 14 presents a summary of alternative passenger vehicle emission reducing devices, and their costs.

Table 15: Effects of enforcing the reduction strategy for pollutants in Taipei

Pollutant	Comment
Total suspended particulates	Reductions achieved mainly from point sources, the control programme for construction sites, and the improvement of the emission test for diesel vehicles.
PM_{10}	Reductions achieved mainly from the examination and spot checks of new automobiles, but also from the emission testing of diesel vehicles and the phase-out of diesel buses.
Oxides of sulphur (SO_X)	Reductions achieved mainly from the control of the sulphur contained in diesel fuel and partly from the control of point sources
Oxides of nitrogen (NO_X), Non-methane hydrocarbons (NMHC), CO	In addition to reductions from fixed sources, NO_X, NMHC, and CO have also been reduced from mobile source. (*e.g.* by enacting stricter emission standards for exhausts). A secondary cause is the effect of exclusive lanes for buses and the chessboard-style road network of bus routes.

Source: Taipei City Environmental Protection Bureau

Figure 18

Taipei has developed a bus lane network of 57 km since March 1998 (at an average cost of US$500,000 per km), in the context of a wider policy framework emphasising: a network of dedicated bus lanes; high quality transfer environments; 'green' buses; Intelligent Transport System applications; transit-oriented development; and air quality and environmental improvements. The bus lane network has also resulted in a reduction in the number and severity of accidents.

Jason Chang, 2002

Box 10: Enforcement and control strategies in Taipei

The Environmental Protection Administration (EPA) of Taiwan is the main regulatory agency that oversees air pollution related policies. The regulatory framework of all air quality management policies are based on the following legislation: the Air Pollution Control Act (1992), Implementation Rules for the Air Pollution Control Act (1993), and the Ordinance for the Management of Agencies in Charge of the Testing of Pollutant Emissions and Noises Produced by Automobiles and Motorcycles (1998). (Taipei's world-leading motorcycle emission standards regime is described in Module 4c: *Two- and Three-Wheelers*.) Since Taipei was reorganized into a municipality, some air quality laws and regulations were amended to address urban air quality issues, and a specialized agency in the Taipei City Government has been set up to take charge of all environmental cleaning jobs, such as pollution control for air and water, control of unpleasant noise, environmental sterilization, and disposal of human manure and garbage. The Technical Division of the Bureau of Environmental Protection (EPB) of Taipei City oversees environmental quality inspections and monitoring.

The head of Taiwan's EPA has made clear his intent to see that strict environmental standards be imposed on many environmentally controversial projects currently under review. Taiwan also is expected to continue its shift away from energy sources such as nuclear power and coal to more environmentally benign sources such as natural gas. In addition, an increasingly powerful environmental lobby intent on pressuring Taiwan's Government into more aggressively enforcing environmental regulations has played a significant role in forming air quality policies. Furthermore, much of Taiwan's environmental future could also depend on its relationship with mainland China, as trade ties are opened wider and political questions are answered.

For the past few years, the Taipei EPB has implemented a program to improve air quality and has succeeded in continuously reducing polluting emissions (Table 15). The major measures promoted to control air pollution include:

- ***Controlling mobile sources***—includes the promotion of low emission vehicles, the enhancement of testing and the elimination of high contamination vehicles, and so on.
- ***Controlling point sources***—reinforces the inspection of businesses such as restaurants, automobile repair shops, laundries, gas stations, and industrial facilities located in the city, as well providing assistance in improving emission controls.
- ***Controlling fugitive sources***—controlling pollutant emissions from construction sites and associated measures such as street-sweeping.
- ***Integrative management project***—overall air quality assessment and capacity building, and public awareness raising.

In order to reinforce the promotion of the National Environmental Protection Project, the EPB focuses on the characteristics of pollution in the city and the goal of reducing air pollutant emissions, and evaluates each enforcing instrument in order to draw up the 'Policy of Restrain Air Pollution in Taipei Municipal'. As mentioned above, apart from a few point and fugitive sources, air pollution in the city mainly comes from motor vehicles. In order to control the mobile sources, the EPB has been formulating progressively stricter standards for vehicle emissions. Compared with the policies of other countries, the standards of Taipei are regarded as relatively strict. However, the experience of other countries has shown that, in addition to controlling mobile source emissions, traffic management practices are an important aspect of the overall transportation strategy. Traffic management schemes can reduce traffic congestion, reduce engine idling time and reduce the number of kilometres travelled for the whole traffic fleet. Also, fuel consumption will be reduced so that total emissions to the atmosphere can be lessened.

With the air-pollution allowance subsidised by the Bureau of Transportation, Taipei city continuously enhances related control measures. The EPB has implemented a number of strategies to control mobile source emissions (Figure 18). These measures have included educating the public to undertake periodical maintenance and examination of their vehicles in order to ensure that the vehicle complies with environmental protection regulations. EPB projects in 2001 included:

- An examination of diesel vehicles exhaust fumes;
- An electric motorcycle promotion program;
- Publicising periodic examinations of motorcycle exhaust (Figure 19);

- Auditing and assessment of motorcycle exhaust;
- Periodic examination of petrol stations in taipei city;
- Controling air pollution from mobile sources through roadside inspection of motorcycles.

Future strategies to control mobile sources in Taipei include:

- Promotion of low-pollution vehicles (electric motorcycles & bicycles, liquefied petroleum gas cars, compressed natural gas buses, and other alternative fuels);
- Surveys on pollution characteristics to facilitate formulating control counter measures;
- Replacement of high-pollution vehicles with stricter emissions standards;
- Promotion of automobile pollution control devices, particularly for diesel emissions;
- Reduction of motorcycle pollutant emissions through regular inspections, regulations and publicity campaigns;
- Medium-to-long term control strategies for mobile sources.

An overall assessment of transportation systems and traffic control strategies has also been done in Taipei (see Figure 18).

In addition to the continual strengthening of emission controls for various air pollutants, the air pollution control strategy in Taipei City will also be required to address the emissions of greenhouse gases (GHGs). The EPB will increase citizens' awareness of climate change issues in order to reduce GHG emissions. Because mobile sources are the primary cause of air pollution in the city, the EPB will co-operate with the other city authorities concerned in order to increase the control of mobile sources and co-ordinate activities. Furthermore, due to advances in technology and lifestyle changes, the EPB is examining the most appropriate management and control measures. The aim of such actions is to maintain citizens' health, enhance quality of life and protect the environment.

Figure 19

Controlling motorcycle emissions is a key part of Taipei's environmental program.

Gerhard Metschies, GTZ Urban Transport Photo CD

6.10 Review of standard setting

The setting of standards should encompass a process involving stakeholders (industry, local authorities, non-governmental organisations and the general public) that assures—as far as possible—social equity or fairness to all the parties involved. It should also provide sufficient information to guarantee understanding by stakeholders of the scientific and economic consequences. The earlier stakeholders are involved, the more likely is their co-operation. Transparency in moving from air quality guidelines to air quality standards helps to increase public acceptance of necessary measures. Raising public awareness of air pollution-induced health and environmental effects (changing of risk perception) serves to obtain public support for the necessary control action, *e.g.* with respect to vehicular emissions. Information provided to the public with regard to air quality during pollution episodes and the risks entailed lead to a better understanding of the issue (risk communication).

Air quality standards should be reviewed and revised regularly as new scientific evidence on the effects on public health and the environment emerges.

6.11 Enforcement of air quality standards: clean air implementation plans

It is the enforcement of air quality standards that ensures that actions are taken to control polluting sources in order to comply with the standards. The instruments used to achieve this goal are Clean Air Implementation Plans (CAIPs). The outline of such a plan is usually defined in regulatory policies and strategies. CAIPs were implemented in several developed countries during the 1970s and 1980s. At that time the air pollutant situation was characterised by a multitude of different types of sources leading to an extremely difficult causal assessment of public health risks with respect to single source or group of sources. As a consequence, and on the basis of the polluters pay principle, sophisticated tools were developed to assess the pollution sources, air pollutant concentrations, health and environmental effects and control measures. The tools also made a causal link between emissions, the air pollution situation and the efficiency of the necessary control measures. The CAIP has proved to be a most efficient instrument for air pollution abatement in developed countries (Schwela and Köth-Jahr 1994).

In developing countries, the air pollution situation is often characterised by a multitude of sources of few types and sometimes few sources. Using the experience obtained in developed countries, the control action to be taken is often very clear. As a consequence, lower monitoring would be sufficient, and dispersion models could help to simulate spatial distributions of concentrations in the case where only limited useful monitoring data are available. Only simplified CAIPs would have to be developed for cities of developing countries or countries in transition. The main polluters at present in many cities of the developing world are old vehicles and some industrial sources such as power plants, brick kilns, and cement factories.

In such situations, a simplified clean air implementation plan could include:

- A rapid assessment of the most important sources (WHO 1993a; b; 1995; GAPF 2008);
- A minimal set of air pollutant concentrations monitors (UNEP/WHO 1994a; c; d; Schwela 2003);
- Simulation of the spatial distribution of air pollutant concentrations using simple dispersion models (WHO/PAHO/WB 1995);
- Comparison with air quality standards;
- Control measures and their costs (WHO/PAHO/WB 1995);
- Transportation and land-use planning.

Examples of successful simplified CAIPs in developing countries are provided in a report on air quality management capabilities in 20 major cities (UNEP/WHO/MARC, 1996), on the 3rd edition of the AMIS CD-ROM for 70 cities (WHO 2001), and in the *Benchmarking Report* of APMA (UNEP/WHO/SEI/KEI 2002b; Schwela *et al.*, 2006).

7. International programs and selected national initiatives

7.1 United Nations Centre for Human Settlements/United Nations Environment Program

The Sustainable Cities Program (SCP) is a joint UN-HABITAT/UNEP project for enhancing capacities in urban environmental planning and management. The program is founded on cross-sector and stakeholder participatory approaches. It promotes good urban governance. Currently the SCP operates in 20 main demonstration and 25 replicating cities around the world, including cities in China, Chile, Egypt, Ghana, India, Kenya, Korea, Malawi, Nigeria, the Philippines, Poland, Russia, Senegal, Sri Lanka, Tanzania, Tunisia, and Zambia. Preparatory activities are underway in Bahrain, Cameroon, Iran, Kenya, Lesotho, Rwanda, South Africa and Vietnam (UNHCS/UNEP 2002).

Important publications of this project include the SCP Source Book Series. In Volume 6 of this series urban air quality management is addressed. This document covers improvement of:

- Information and expertise for AQM;
- Strategies, action planning, and decision making;
- Implementation and institutionalisation.

Case studies for Shenyang, Manila, and Colombo illustrate the approach chosen in the SCP project (UNHCS/UNEP 2001). In 2004, the path from a city demonstration project to a national programme for environmentally sustainable urban development was demonstrated for Tanzania (UN-HABITAT/UNEP 2004). A recent report addresses the challenges of rapid urbanization in Zambia (UN-HABITAT/UNEP 2009).

7.2 World Meteorological Organisation

The WMO GAW Urban Research Meteorology and Environment (GURME) project was started in 2000 in response to the requests of the National Meteorological and Hydrological Services (NMHSs). The WMO established GURME as a means to enhance the capabilities of NMHSs to handle meteorological and related aspects of urban pollution. NMHSs have an important role to play in the study and management of urban environments because they collect information and have capabilities that are essential to the forecasting of urban air pollution and the evaluation of the effects of different emission control strategies. More details about the GURME program can be found at its website (GURME 2002).

7.3 United Nations Environment Program/World Health Organization: Global Environmental Monitoring System Air (GEMS/AIR)

GEMS/AIR evolved from a World Health Organization urban air quality monitoring pilot project that started in 1973. From 1975 to 1995, the World Health Organization (WHO) and the United Nations Environment Program (UNEP) jointly operated the program as a component of the United Nations system-wide Global Environment Monitoring System (GEMS). GEMS is a component of the UN Earthwatch system.

The original objectives of GEMS/AIR were to:

- Strengthen urban air pollution monitoring and assessment capabilities in participating countries;
- Improve the validity and comparability of data amongst cities;
- Provide global assessments on levels and trends of urban air pollutants, and their effect on human and ecosystem health;
- Collect air pollution concentration data for sulfur dioxide and suspended particulate matter.

Between 1973 and 1995 GEMS/AIR was the only global program which provided long-term air pollution monitoring data for cities in developing countries. Thus the program enabled the production of global assessments of the levels and trends of urban air pollution and air pollution management capabilities.

Numerous papers have been published in the past 20 years by GEMS/AIR, the most recent ones being:

- Urban air pollution in megacities of the world, 1992;
- GEMS/AIR methodology review handbook series, 1994/95;
- GEMS/AIR city air quality trends 1992/93;
- GEMS/AIR report on air quality management capabilities of cities, 1996.

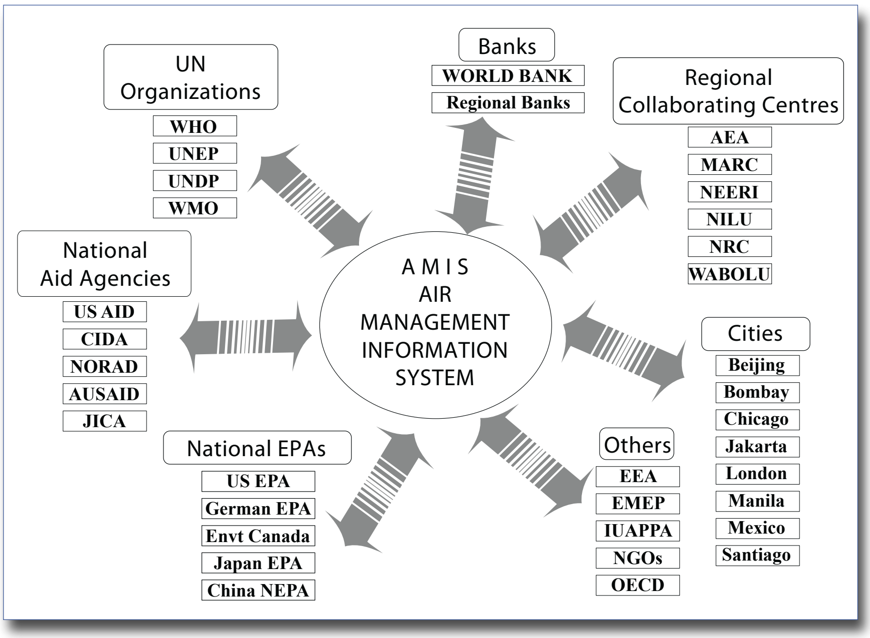
The GEMS/AIR program was terminated in 1997.

7.4 World Health Organization: Air Management Information System

The Air Management Information System (AMIS), a program set up by WHO as a successor to the UNEP/WHO GEMS/AIR program, provided valuable information on air pollutant monitoring and management in major and megacities (WHO 2001). Unfortunately, the AMIS programme was terminated in 2003. AMIS was a set of databases that was developed by WHO under the umbrella of the Healthy Cities Programme (Figure 20). The objective of AMIS was to transfer information on air quality management (air quality management instruments used in cities, ambient air pollutant concentrations, health effects, air quality standards, rapid emission assessment tools, and global, regional and national estimates of the burden of disease due to air pollution) between countries and cities. In this context, AMIS acted as a global air quality information exchange system. AMIS program activity areas included:

- Co-ordinating databases with information on air quality issues in major and megacities;
- Acting as an information broker between countries;

Figure 20
The Global Air Quality Partnership.



- Providing and distributing technical documents on air quality and health;
- Publishing and distributing trend reviews on air pollutant concentrations;
- Organising training courses on air quality and health.

AMIS provided a set of user-friendly Microsoft Access based databases. A core database contained summary statistics of air pollution data such as annual means, 95-percentiles, and the number of days on which WHO guidelines are exceeded. Any compound for which WHO air quality guidelines exist can be entered into the open-ended database. Data handling is easy and data validation can be assured with relatively little means. In the latest version, data (mostly from 1986 to 1998) from about 150 cities in 45 countries were represented (WHO 2001).

7.5 World Bank: Urban Air Quality Management Strategy (URBAIR)

The World Bank, through the Metropolitan Environmental Improvement Program (MEIP), started URBAIR in 1992. The first phase of URBAIR covered five cities Mumbai (Bombay), India; Jakarta, Indonesia; Kathmandu, Nepal; Metro Manila, Philippines; and Colombo, Sri Lanka. The URBAIR studies are based on readily available data and reports along with input from workshops and missions conducted in 1993–94 by local consultants and experts from the Norwegian Institute for Air Research (NILU) and the Netherlands' Institute for Environmental Studies (IES). This effort resulted in this action plan for air pollution abatement (World Bank 1998).

URBAIR is an international collaborative effort involving governments, academia, international organisations, NGOs, and the private sector. Its main objective is to assist local institutions in developing action plans which would be an integral part of the air quality management system for metropolitan regions. A technical compendium, the *URBAIR Air Quality Management Strategy and Action Plan Guidebook*, has been designed for urban environmental policy makers (World Bank 1997a). The guidebook details the steps involved in an air quality management system and provides details on air quality modelling, choices of abatement measures, and how cost-benefit analysis is used to choose appropriate measures. According to the guidebook, the components of an action plan are: *assessment*, *action*, *monitoring* and *evaluation*.

Four city-specific URBAIR studies in Mumbai, India; Manila, Philippines; Jakarta, Indonesia; and Kathmandu, Nepal were published, intended to be used by local institutions in conjunction with the guidebook to formulate policy decisions and to begin their own investment strategies (World Bank 1997b; c; d; e). Two papers issued at the same time address issues of clean fuels for Asia (Walsh and Shah 1997) and successful conversion to unleaded gasoline in Thailand.

7.6 World Bank: Clean Air Initiative

The Clean Air Initiative (CAI) has been designed in the context of the Bank's overall urban strategy, which is to work with both national and local governments to develop, among other things, "livable cities […] ensuring that the poor achieve a healthful and dignified living standard, […] addressing environmental degradation".

CAI's mission is to advance innovative ways to improve air quality in cities by sharing knowledge and experiences through partnerships in selected regions. CAI partners and participants foster actions to improve air quality in cities. The initiative brings together a range of expertise in urban development, transport, energy reform, environmental management and environmental health (World Bank 2002a). The Initiative is currently active in three regions:

- Asia (World Bank 2002b; CAI-Asia 2008);
- Latin America (World Bank 2002c; CAI-LAC 2007);
- Sub-Saharan Africa (World Bank 2002d; CAI-SSA 2005);

Goals of the CAI program include:

- Sharing knowledge and experiences on air quality management;
- Improving policy and regulatory frameworks at the regional level;
- Assisting cities in implementing integrated air quality management systems;
- Capacity building and information-sharing;
- Promotion of clean technologies.

The Clean Air Initiative in Cities of Europe & Central Asia, CAI-ECA, launched in 2001 is no longer active (World Bank 2001;).

7.7 UNEP/WHO/SEI/KEI: air pollution in the megacities of Asia

The Air Pollution in the Megacities of Asia (APMA) project was a joint effort by UNEP and WHO in collaboration with the Korea Environment Institute (KEI) and the Stockholm Environment Institute (SEI) to benchmark urban air quality management and practice in major and megacities of Asia. APMA was built upon UNEP/WHO efforts on air pollution in Megacities under the Urban Air Quality Monitoring Program (GEMS/Air), which formed part of the UN Global Environment Monitoring System (GEMS), and the WHO Air Management Information System AMIS. The APMA project focused on the development of policy to address urban air pollution in Asian megacities. It aimed to increase the capacity of governments and city authorities to deal with urban air pollution issues by developing regional action plans and establishing an urban air pollution network for Asian Megacities (UNEP/WHO/SEI/KEI 2002a).

APMA was funded by the Korea Ministry of the Environment (MOE) and the Swedish International Cooperation Development Agency (Sida) as part of their Regional Air Pollution in Developing Countries (RAPIDC) Program (UNEP/WHO/SEI/KEI 2002a). APMA terminated in 2006 with the publication of the review of the Urban Air Quality in 20 Asian Cities (Schwela *et al.,* 2006).

Box 11: United Nations Economic and Social Commission for Asia and the Pacific: Kitakyushu Initiative for a Clean Environment

In September 2000, the Kitakyushu Initiative for a Clean Environment was adopted at the 4th Ministerial Conference on Environment and Development in Asia and the Pacific (MCED) as a mechanism to achieve tangible progress in environmental quality and human health in urban areas in Asia and the Pacific Region. Since then, the Kitakyushu Initiative Network has developed thematic seminars and demonstration projects on successful policy measures and information dissemination under the auspices of the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). Based on the review of its achievements during 2000 to 2005 the MCED 2005 has endorsed the Action Plan for activities from 2005 to 2010 (UNESCAP/IGES/MOE 2006). This second cycle of the Kitakyushu Initiative is supposed to be instrumental in enhancing the capacity of local governments in Asia and the Pacific through promotion and application of integrated approaches to address urban environmental management and the promotion of socioeconomic livelihoods at the local level. The expected output of this cycle will be the compilation of successful urban policies and practices by participating cities, and models of effective urban strategies, policies and programmes in environmental management.

Box 12: Urban air quality management in Europe

The objectives of the Framework Directive 96/62/EC on ambient air quality assessment and management (EU 1996) are to outline a common strategy to:

- Establish emission limits to improve ambient air quality;
- Assess ambient air quality in the eu on the basis of common methods and criteria;
- Ensure adequate information is made available to the public;
- Maintain ambient air quality where it is good and improve it in other cases.

The Framework Directive (EU 1996) consider air quality standards for already regulated atmospheric pollutants (SO_2, NO_2, PM, Pb and O_3) and for benzene, carbon monoxide, polycyclic-aromatic hydrocarbons, cadmium, arsenic, nickel and mercury. The Framework Directive and its Daughter Directives (EU 1996; EU 1999; EU 2000; EU 2002; EU 2004) include a timetable for the implementation of air quality standards for 12 individual pollutants. The objectives of the daughter directives are to harmonise monitoring strategies, measuring methods, calibration and quality assessment methods to achieve comparable measurements throughout the EU and good information to the public. Table 4.4 in Annex 3 presents the limit values for different pollutants covered by the Framework and daughter directives.

The European Union (EU), in its programme for Clean Air for Europe (CAFÉ) has developed a thematic strategy for improving air quality in Europe. This strategy is based on four elements (EU 2001):

1. Developing emission limits for ambient air quality;
2. Combating the effects of transboundary air pollution;
3. Identifying cost-effective reductions in targeted areas through integrated programmes;
4. Introducing specific measures to limit emissions.

The main elements of the programme are:

- Review the implementation of air quality directives and effectiveness of air quality programmes in the Member States.
- Improve the monitoring of air quality and the provision of information to the public, including the use of indicators; priorities for further action, the review and updating of air quality standards and national emission ceilings and the development of better systems for gathering information, modelling and forecasting.

The EU policy was recently updated in Directive 2008/50/EC which lays down measures aimed at the following (EU, 2008):

5. Defining and establishing objectives for ambient air quality designed to avoid, prevent or reduce harmful effects on human health and the environment as a whole;
6. Assessing the ambient air quality in Member States on the basis of common methods and criteria;
7. Obtaining information on ambient air quality in order to help combat air pollution and nuisance and to monitor long-term trends and improvements resulting from national and Community measures;
8. Ensuring that such information on ambient air quality is made available to the public;
9. Maintaining air quality where it is good and improving it in other cases;
10. Promoting increased cooperation between the Member states in reducing air pollution.

In 16 annexes the Directive defines data quality objectives; reinforces limit values and upper and lower assessment thresholds for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter (PM_{10} and $PM_{2.5}$), lead, benzene and carbon monoxide in urban areas; regulates the location of sampling points and measurements at rural background locations; specifies the minimum number of sampling points; prescribes the reference methods for concentration measurements; appoints target values for ozone and criteria for classifying and locating sampling points and the minimum number of sampling points for this compound; sets alert thresholds for sulphur dioxide and nitrogen dioxide; sets critical values for the protection of the vegetation and national exposure reduction targets for $PM_{2.5}$; outlines the content of national air quality plans; and regulates raising public awareness.

Box 13: GTZ approach to air quality management

For more than 15 years GTZ has provided advisory services for air quality management projects in more than 20 countries. The GTZ's approach to Air Quality Management (AQM) is based on a comprehensive set of integrated services which include:

- ***Improving institutional and legal frameworks*** through political consensus-building, institutional and legal reforms, and promoting cooperation between major actors (governmental and non-governmental).
- ***Introducing and monitoring emission and fuel quality standards***, including vehicle inspection & maintenance.
- ***Strengthening the capacities*** (qualification, know how) of all relevant actors in AQM, including ministries, regulatory authorities, NGOs, the media, associations and research institutions.
- ***Improving air quality information*** through monitoring units, air quality information systems, dispersion & trend modeling, etc.
- ***Promoting the integration of AQM in urban planning and transport planning*** through supporting the elaboration and implementation of long-term AQM strategies and sustainable urban development strategies.
- ***Improving social communication and public participation*** to create ownership by the public and the media, and empower people to support AQM strategies.
- ***Promoting international cooperation*** through networking, shared experience, and joint international initiatives such as the World Bank's Clean Air Initiatives, where GTZ has been member of the steering committee in Latin America and plays an active role in CAI Asia.

At present there are more than 20 projects covering a wide range of air pollution issues, including:

- Integrated AQM stategies for megacities, such as Mexico City (see GTZ 2002), Santiago de Chile (see Box 9), Kuala Lumpur, and other cities. These projects cover a wide range of the above AQM service modules.
- Legal reforms in various countries in Eastern Europe. Twinning projects aim also at harmonizing the member candidates' legal systems with the Acquis Communautaire of the EU.
- Clean air strategies and environmental action planning, *e.g.* in Macedonia, Brasil, India. Clean air measures are part of many local and national environmental strategies that also cover other environmental issues such as water, waste, sanitation.
- Sustainable urban development in Golo, Palembang, Bogor, Yogyakarta, Delhi, Cochin, Yangzhou, Changzhou/China, etc. The eco-city approach aims at a comprehensive set of urban policy and planning measures to support a sustainable urban development (thereby including many strategies as represented in this *Sourcebook*).
- Other approaches with components of AQM include a large number of projects for eco-Industrial development, eco-efficient production and eco-efficient energy, cleaner coal and household energy.

For more information and contact details please see http://www.gtz.de.

8. Conclusions

Given the economic consequences of air pollution, such as increased expenses of health services and damaged ecosystems that are necessary for the economy, and reduced productivity from workers with pollution-related illnesses, it is clear that there are benefits to the timely redress of pollution problems. Although control mechanisms may be very costly initially, in the end the costs will be recovered. For example, when the United States shifted from the use of leaded fuel to unleaded fuel, it saved US$10 for every $1 invested in the process of conversion due to lower health costs, reduced need for engine maintenance, and increased fuel efficiency (WRI/UNEP/UNDP/WB 1998). The same is true for switching to cleaner forms of energy, which will diminish dangerous fossil fuel emissions. Solar energy, for example, is expensive upon installation, but the cost of maintaining solar panels is very low. In the long run, the money that is saved from reduced fossil fuel consumption is greater than the money that was spent to install the solar panels.

Reductions in fossil fuel consumption, and hence reduction in atmospheric pollution, can come from a number of areas. To begin, fuel prices should reflect the actual costs of fuel consumption on society. Currently fuel prices are far too cheap, which encourages over-consumption of a non-renewable resource.

Most fossil fuel combustion takes place in the transportation sector. Therefore, governments need to place restrictions on the use of vehicles while improving the efficiency and availability of public transportation and non-motorised alternatives. This method has worked extremely well in Singapore, where air pollution levels comply with the air quality standards of the US Environmental Protection Agency. The well-regulated pollution situation can be attributed to early recognition of the problem and efficient and informed policy and management practices (Roychoudhury *et al.,* 2000; Koh Kheng-Lian, 2002).

The Singapore government sought to address the pollution problem from its source: excessive vehicle use. Therefore, it placed severe economic restrictions on the ownership and use of automobiles, making it far too expensive for the average person to use private transportation.

For now, however, fossil fuel use is such an integral part of life that it is necessary to control the rate of emission and the toxic composition of emissions either before, during, or after combustion. Prior to combustion it is possible to control toxic emissions through the use of low-sulfur or sulfur-free fuels (including natural gas), fuel cleaning, and unleaded petroleum. During combustion, pollutants should be controlled by using low NO_X burners, or fluidised bed combustion which is known to reduce both NO_X and SO_2 emissions. Post-combustion, catalysts should be used in power stations and vehicles to reduce NO_X. Scrubbers should also be used to remove the pollutants from gaseous emissions after the burning of fossil fuels.

When nearly every nation in the world has problems with air pollution, the problem can be termed a global issue. To redress the global nature of the problem, each nation has to make efforts to control their own pollution. At the national level, information about the environment, health, economics, and law should be reviewed in order to develop policy that is practical for local governments. Meanwhile, health clinics should be provided with information about air pollution-related illnesses to treat those who are already affected by pollution and to educate the community about the adverse health effects of air pollution and the best ways to avoid exposure (UNEP/UNICEF 1997).

Both health and environmental problems are multi-causal. To successfully solve these types of problems, national governments need to promote the coordination of activities and information between the ministries or departments that deal with each aspect of these problems. More collaboration is also needed between government agencies and non-governmental or community-based organisations that often have more grassroots experience and are thus more familiar with real-life conditions (UNEP/UNICEF, 1997).

Locally, monitoring health conditions will provide information about the severity of air pollution and provide input into deciding what needs to be done to address these problems. Moreover, local governments need to provide the knowledge for people to protect themselves from air pollution.

Environmental issues cannot be addressed in isolation; protection of the environment must be undertaken while keeping in mind a number of social and economic factors, including health, and economic policy. Collaboration between stakeholders and government ministries is necessary for successful control of air pollution.

Air pollution control also cannot be achieved by ordering industries and vehicle owners to change their means of production or ways of life. Incentives must be provided in order to persuade compliance with air pollution regulations. In the case of industries, incentives can come in the form of tradeable permits and other market-oriented policies. People, on the other hand, can be convinced to protect the environment if they become aware of or feel the effects of health problems that accompany air pollution.

Both developed and developing countries need to adopt environmentally friendly technologies, change patterns of consumption and develop alternative renewable fuel sources. In many cases, including in the urban transport sector, developing countries can learn from the successes and failures of the developed world.

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Selected abbreviations used in this module

CAIP	Clean Air Implementation Plan
CO	Carbon monoxide
ETS	Environmental tobacco smoke
HC	Hydrocarbons
NO_X	Oxides of nitrogen
NO_2	Nitrogen dioxide
O_3	Ozone
PAH	Polycyclic aromatic hydrocarbons
Pb	Lead
PM	Particulate matter
PM_{10}	Particles less than 10 microns in diameter (1 micron = 0.001 millimetres)
$PM_{2.5}$	Particles less than 2.5 microns in diameter
QA/QC	Quality assurance and control
SPM	Suspended particulate matter
SO_2	Sulfur dioxide
TSP	Total suspended particulates
UBA	Umweltbundesamt, German Federal Enviromental Agency
UNEP	United Nations Environment Programme
US EPA	United States Environmental Protection Agency
WHO	World Health Organization
WSSD	World Summit on Sustainable Development

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