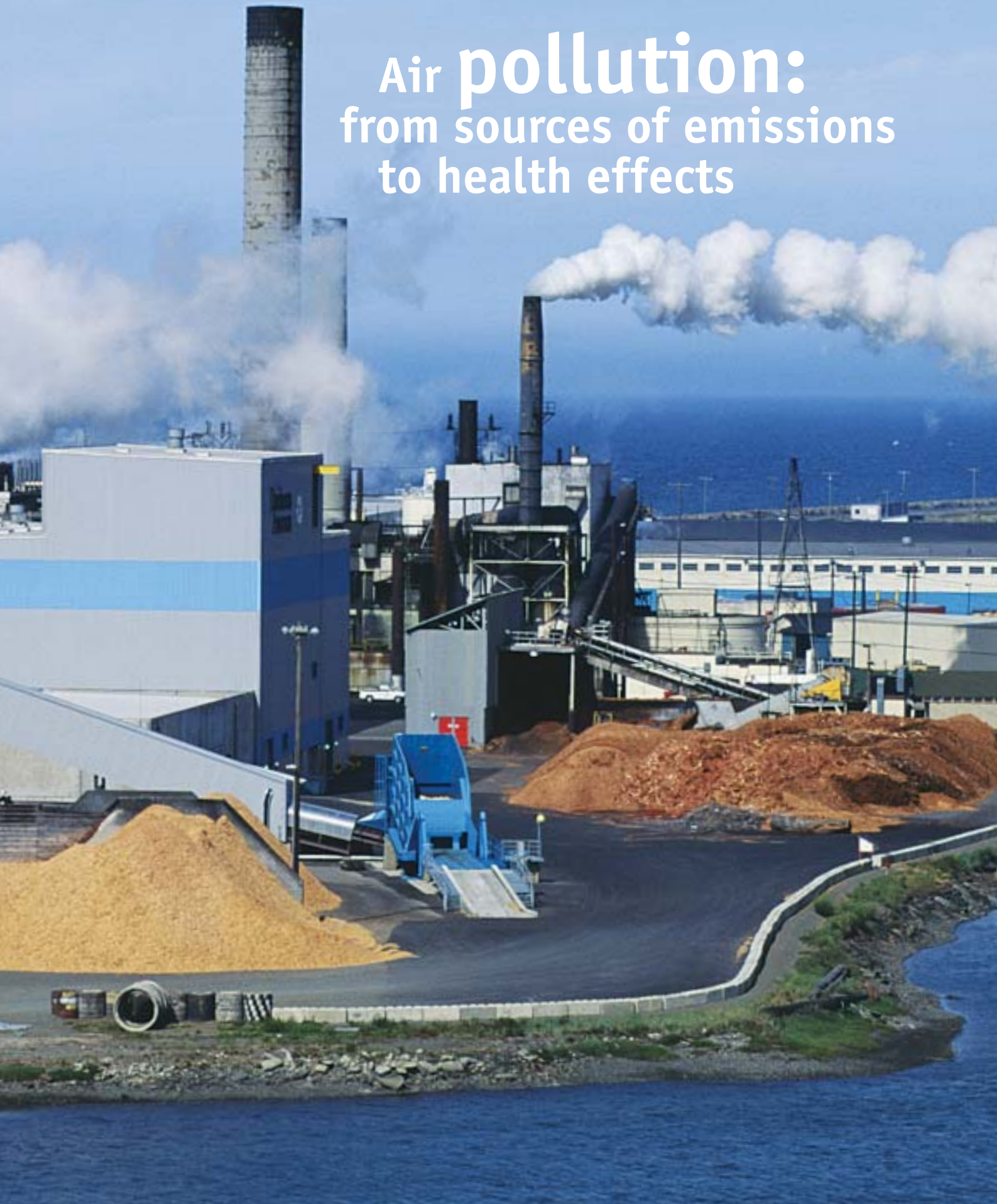


# Air **pollution:** from sources of emissions to health effects





## Educational aims

- ▶ To provide a thorough presentation of sources, dispersion and transformation of major air pollutants.
- ▶ To describe the health effects of these air pollutants.
- ▶ To explain the differences between emissions, immissions, exposure and absorbed dose.
- ▶ To help readers to understand what is at stake in the topical scientific and political debate on air pollution.

## Summary

Air pollution, particularly in urban areas, constitutes a public health concern, as it has a harmful effect on the health, survival and activities of humans and other living organisms.

Here, the main types of air pollution commonly found in urban environments are presented, along with their sources, levels of emissions, mechanisms of dispersion, transformation, concentrations in ambient air (=immissions), and effects on the environment and health. In particular, the concepts of exposure, absorbed dose and individual susceptibility are explained. The recent evolution in air pollutant emissions and immissions due to the growing weight of road traffic is also described. Finally, European air quality criteria are highlighted.

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◀ All chemical, biological and physical agents that modify the natural characteristics of the atmosphere are referred to as "air pollutants". Air pollutants arise both from natural processes (volcanic activities, oceans, forests, etc.) and human activities (fossil fuel combustion, transportation, power plant emissions or emissions from other industrial processes). Air pollutants can be classified as either primary or secondary. Primary pollutants are substances directly produced by a process, such as ash from a volcanic eruption or carbon monoxide gas from a motor vehicle exhaust. Primary pollutants can be transformed in the lower atmosphere by solar radiation and heat into secondary pollutants, such as ozone (O<sub>3</sub>) and other photochemical pollutants.

This article briefly describes major air pollutants, by presenting their sources, dispersion, transformation, immission (concentration of air pollutants in the ambient air), and potential effects on health and the environment.

## Sources of air pollution

Sources of air pollution [1] include natural sources [2] and human-made sources [3].

### Natural sources

Naturally occurring particulate matter (PM) includes dust from the earth's surface (crustal material), sea salt in coastal areas and biological material, in the form of pollen, spores or plant and animal debris [1]. Volcanic eruptions can introduce very important quantities of gases and particles into the atmosphere. For example, the Etna volcano emits 3,000 tons of sulphur dioxide (SO<sub>2</sub>) on an average day and up to 10,000 tons during periods of great activity. During the cataclysmic eruptions of the Tambora in 1815 in Indonesia, 100 billion tons of volcanic products were ejected into the atmosphere, 300 million tons of which reached

### Key points

- ▶ Immissions (=concentration of air pollutants in the ambient atmosphere) result from the intensity and the type of emissions of air pollutants, the dispersion of air pollutants and their transportation.
- ▶ The main air pollution indicators are SO<sub>2</sub>, NO<sub>x</sub>, PM, CO, VOC and O<sub>3</sub>.
- ▶ Road traffic has become the first source of air pollution in urban areas.
- ▶ Health effects caused by air pollutants depend on the absorbed dose, the type of pollutants and the individual susceptibility.

the stratosphere, which resulted in a mean temperature fall of  $\sim 0.7^{\circ}\text{C}$  over the whole Earth. In some rural areas, periodic forest fires produce large amounts of PM.

Other natural sources of air pollution include: thunderbolts, which produce significant quantities of oxides of nitrogen (NO<sub>x</sub>); algae on the surface of the oceans, which give out hydrogen sulphide (H<sub>2</sub>S); wind erosion, which introduces particles into the atmosphere; and humid zones, such as swamps, peat-bogs or little deep lakes, which produce methane (CH<sub>4</sub>).

Low concentrations of O<sub>3</sub> occur naturally at ground level, formed in the presence of sunlight by reactions between NO<sub>x</sub> and volatile organic compounds (VOCs).

### Human-made sources

In urban areas, most air pollution comes from human-made sources. Such sources can be classified as either mobile (cars, trucks, air planes, marine engines, *etc.*) or point source (factories, electric power plants, *etc.*).

To date, road traffic constitutes the major source of air pollution in the large cities of industrialised countries. Combustion of carbon-constituted fuels (coal, fuel oil, wood, natural gas) is never complete, and it produces carbon monoxide (CO) and hydrocarbons. NO<sub>x</sub> result from the combination of air nitrogen and oxygen from combustion of fossil fuels contained in motor fuel at high temperature.

Human activities have increased the amount of VOCs due to petroleum, chemical industries and transportation, and NO<sub>x</sub> from combustion in power stations and automobiles. Consequently, O<sub>3</sub> is more concentrated and more smog occurs in densely populated and industrial regions. Human

activities contribute to total ambient PM. In urban environments, particles arise mainly as a result of combustion from mobile and stationary sources. Coal and sulphur from fuel oils oxidise into SO<sub>2</sub>. These are fuels that are used to move, warm up and get the necessary energy to the many industrial processes. Moreover, the industry produces some specific pollutants as waste, such as fluorine derivatives or aluminium.

Ore treatment gives out "heavy" metals, such as cadmium, zinc and lead. Mercury is produced by domestic garbage incineration. Agriculture, by the utilisation of nitrogen fertilisers, generates nitric oxide (N<sub>2</sub>O), a greenhouse effect gas, and ammonia (NH<sub>3</sub>), which participate in the processes of acidification. CH<sub>4</sub>, another greenhouse effect gas, is produced mainly by digestion and evacuation of farming animals.

### Sources of main air pollution indicators

There are too many pollutants in the atmosphere for all of them to be monitored. Among them, some pollutants are monitored because they are characteristic of a particular pollution (released by industrial plants or motor vehicles) and because they are known or suspected to cause detrimental effects on the environment and/or health. These pollutants are called air pollution indicators [4–6].

Major indicators monitored in Europe include:

- Sulphur dioxide (SO<sub>2</sub>)
- Nitrogen oxides (NO<sub>x</sub>)
- Particulate matter (PM<sub>10</sub>, PM<sub>2.5</sub>)
- Ozone (O<sub>3</sub>)
- Carbon monoxide (CO)
- Volatile organic compounds (VOCs)
- Several toxic metals, such as lead, arsenic, cadmium, nickel or mercury ("quicksilver").

**Figure 1**  
The structure of this article is based on the air pollutant cycle.

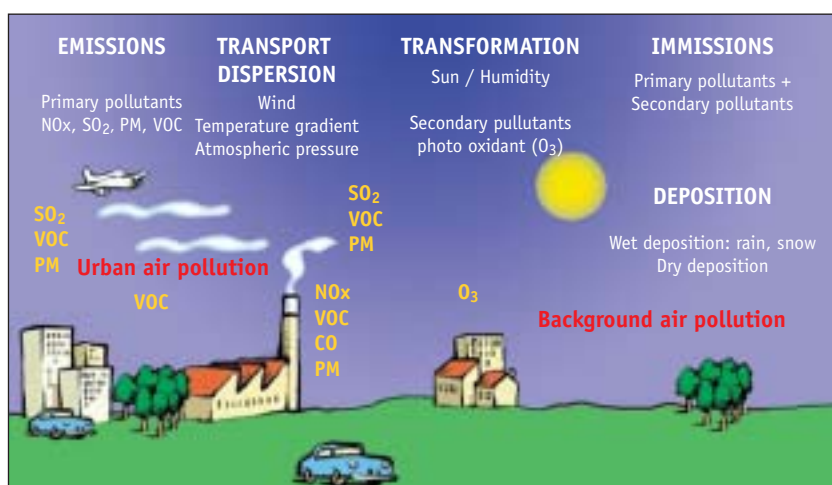


Figure 2 provides an example of the sectorial distribution of French emissions in 2002. Data is taken from The Centre Interprofessionnel Technique d'Etude de la Pollution Atmosphérique (CITEPA; [Inter-professional Technical Centre for Research into Air Pollution]).

CITEPA regularly produces estimations of quantities emitted into the atmosphere from different sources for various substances; [www.citepa.org/emissions/index\\_en.htm](http://www.citepa.org/emissions/index_en.htm).

Emission estimations are produced using a recognised methodology based on the CORINAIR system, developed by the European Environment Agency.

## Main air pollution indicators

### Sulphur dioxide (SO<sub>2</sub>)

In France, 85% of SO<sub>2</sub> emissions come from the use of sulphur-containing fossil fuels (fuel oil and coal). These emissions are mainly released into the atmosphere by petroleum refining (24% of emissions in mainland France in 2002), production of electricity (16%) and heating systems (figure 2). The diesel motor vehicle sector is also responsible for a minor part of SO<sub>2</sub> emissions.

### Nitrogen oxides (NO<sub>x</sub>)

In 2002, road traffic was responsible for releasing 48% (16% for diesel truck traffic) of NO<sub>x</sub> emissions in mainland France, followed by agriculture/forestry, the manufacturing industry and energy transformation (figure 2).

### Particulate matter (PM)

PM is a complex mixture of solid particles and liquid droplets suspended in the air that vary in size, composition and concentration. PM is usefully classified by size. PM with a mass median aerodynamic diameter <10 µm (PM<sub>10</sub>; big particles) can stay in the air for minutes or hours and can travel as little as 100 yards or as much as 30 miles, while PM<sub>2.5</sub> (fine particles) are lighter and stay in the air for days or weeks longer and travel farther. The sources of airborne PM comprise of the manufacturing industries, public buildings and the work sector, specifically agriculture/forestry (particularly ploughing) (31% of PM<sub>10</sub> emissions in mainland France in 2002), domestic heating systems and the incineration of waste. However, airborne particles are also released by motor vehicles, mainly diesel engines (13% of the PM<sub>10</sub> emissions in mainland France in 2002 and 20% of the PM<sub>2.5</sub> emissions) (figure 2).

### Ozone (O<sub>3</sub>)

Most O<sub>3</sub> comes from vehicular traffic during summertime.

### Carbon monoxide (CO)

CO is a gas that comes from incomplete combustion. In 2002, 34% of CO emissions in mainland France were generated by road traffic. The manufacturing industries and the residential/tertiary sector both come in second position, contributing 26% of emissions. Urban, collective or individual heating constitute the main part of the residential/tertiary sector contribution (figure 2).

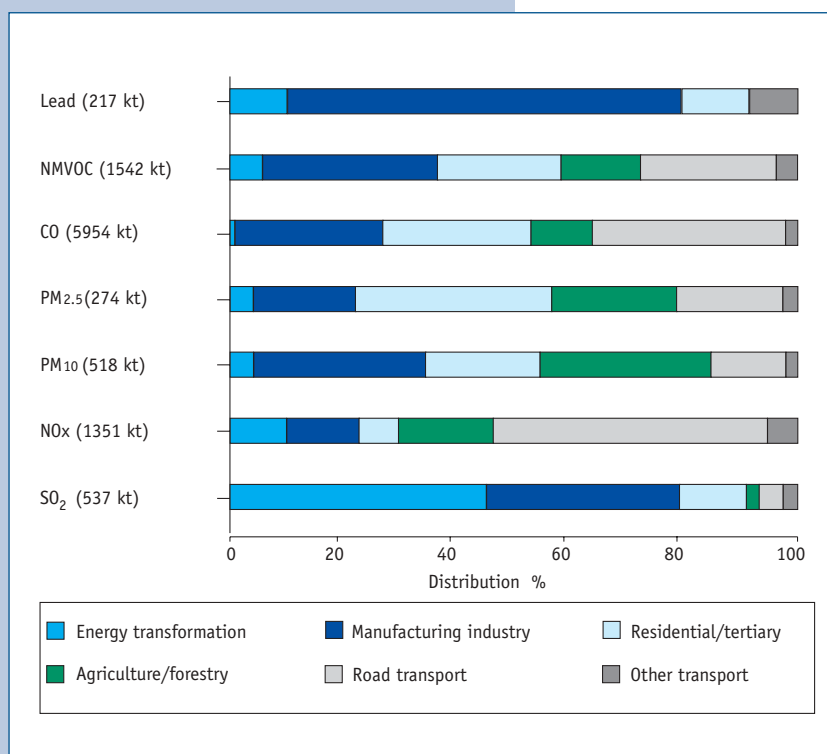
### Volatile organic compounds (VOCs)

The number of VOCs is huge and a list is available on the web. Emissions from burning coal, oil and gasoline, and evaporation at gasoline service stations, and from solvents, cleaners and paints, all contribute to the baseline level of different VOCs found in outdoor air. Some VOCs are also released from tobacco smoke. The three main sources of VOC are road traffic (24% of non-methane VOC (NMVOC) emissions in mainland France in 2002), domestic or industrial use of painting, varnish or glue, and evaporation of hydrocarbons (31% for manufacturing industries and 22% for residential/tertiary) (figure 2). VOC levels in urban areas, such as New York City (NY, USA), fluctuate widely; large differences occur because of both location (near idling cars or trucks *versus* on the waterfront) and time (rush hour *versus* middle of the night).

### Lead

Lead is generated by the manufacturing industry (70% of lead emissions in mainland France in 2002), the metallurgy industry in particular (figure 2).

**Figure 2**  
Sectoral distribution of emissions in 2002 in mainland France.



### The importance of road traffic in urban air pollution

In urban areas, road transport is currently the major source of air pollution [7]. For example, in the Paris (France) region, road transport was the main source of CO, NO<sub>x</sub> and PM<sub>10</sub> in 2000, with 76.9% of CO emissions, 52.2% of NO<sub>x</sub> emissions and 36.2% of PM<sub>10</sub> emissions (figure 3). Road transport is the second source of NMVOC (28.6% of emissions), after the domestic, tertiary or industrial use of solvents (41.4%).

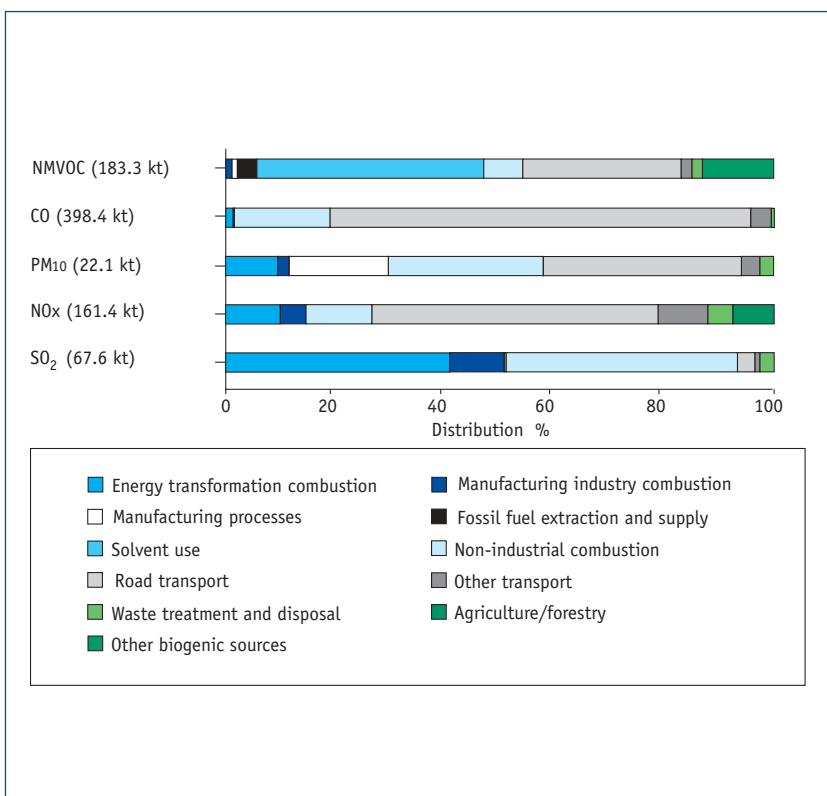
Figure 3 provides an example of the sectorial distribution of emissions for the main pollution indicators in 2000, in the Paris region of France.

Data is taken from the association AIRPARIF, [www.airparif.asso.fr/pollutants/default.htm](http://www.airparif.asso.fr/pollutants/default.htm), which was created in 1979 and is in charge of monitoring air quality throughout the Paris region, which includes 11 million inhabitants (19% of France's total population) scattered over ~1,300 districts and covering a surface area of 12,000 km<sup>2</sup>.

### Evolution of air pollutant emissions

The distribution of emissions between the different sectors of activity changed in France between 1960 and 2002, as is the case for all developed countries (figure 4) [6].

**Figure 3**  
Sectorial distribution of emissions for the main pollution indicators in 2000 in the Paris region of France.



Data shown in figure 4 are taken from (CITEPA). The emissions of SO<sub>2</sub>, NO<sub>x</sub>, PM<sub>10</sub>, CO, NMVOC and lead have been reduced. Emissions from industry have considerably decreased, while the tendency is less clear for road transport.

Emissions from industry have significantly decreased in developed countries, so that road traffic, instead of industry, has become the main source of air pollutant emissions. Since 1980, there has been an important reduction in all sources of SO<sub>2</sub> (60% reduction between 1980 and 1990, and 83% between 1980 and 2002), due to the implementation of the nuclear power programme and the use of fuel containing less sulphur.

Since 1991, there has been a reduction of 31% in NO<sub>x</sub> emissions, partly due to the use of catalytic converters. Since 1993, the part played by road transport has begun to slightly decrease, even if road transport remains the primary source of NO<sub>x</sub> emissions.

Emissions of PM<sub>10</sub> were reduced by 17% between 1990 and 2002. However, the contribution of road transport to PM<sub>10</sub> emissions has not changed (12% in 1990; 13% in 2002), due to the increased activity of diesel vehicles.

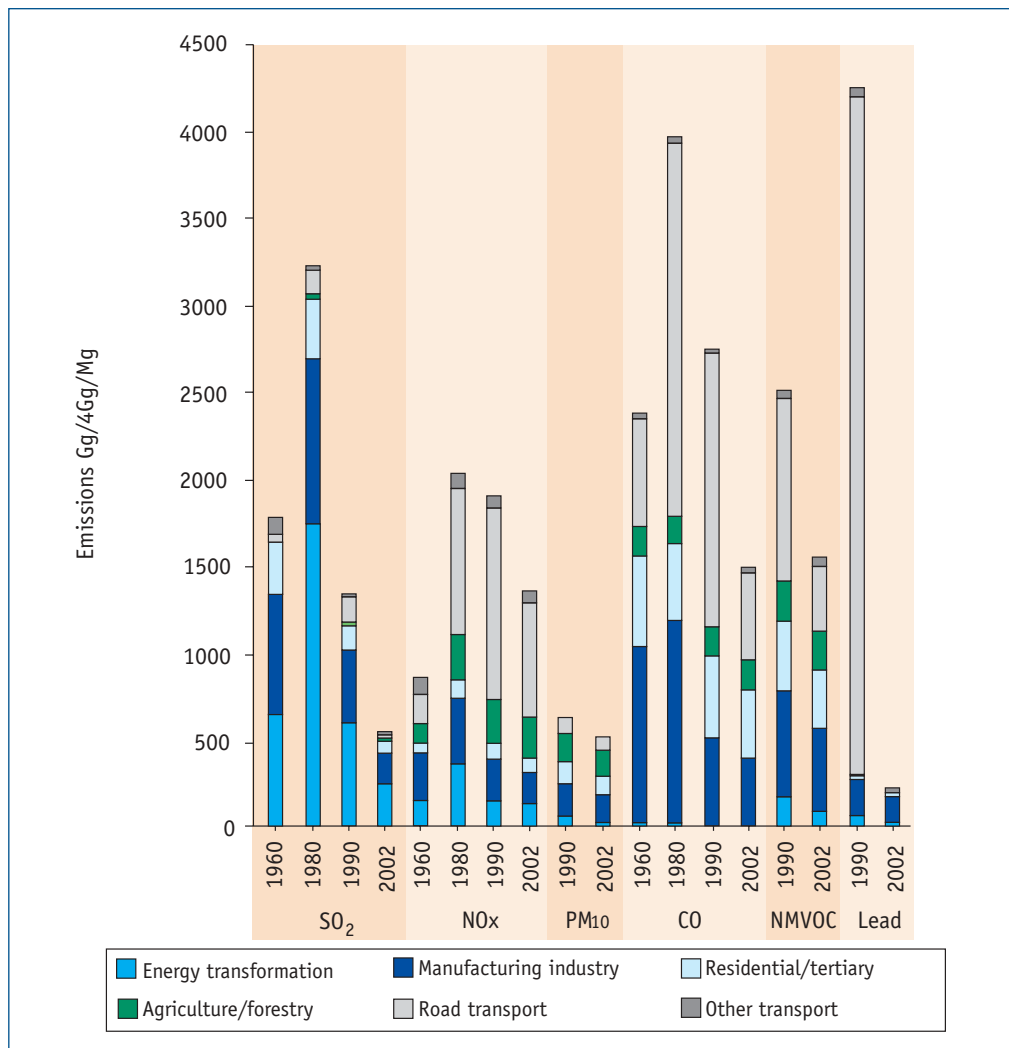
The emissions of CO have constantly diminished since 1973, and were reduced by a third between 1973 and 2002. Whilst the manufacturing industry was the major source of CO followed by road transport in 1960, road transport was moved up to first position in 2002.

Since 1990, lead emissions have been dramatically reduced. Between 1990 and 1999, road traffic was the major source of lead emissions (91% in 1990; 68% in 1999), while road traffic only generated 3% of lead emissions in 2000 and 0% since 2001.

There was a reduction of 38% in NMVOC emissions between 1990 and 2002. In 1990, road transport was the first source of NMVOC emissions, while in 2002 road traffic was second after the manufacturing industry. The decrease in the role of road transport is mainly due to the use of catalytic converters since 1993.

## Dispersion and transformation of pollutants

Air pollution is not only determined by the type and intensity of the emissions. Meteorology and the climate, as well as the topography of the site, all have a major influence on the dispersion and



**Figure 4**  
Changes in emissions per sector of activities in mainland France, 1960–2002.

transformation of pollutants [3, 7]. The concentration of pollutants in the low layers of the atmosphere depends on the atmospheric pressure, the wind and the temperature. Atmospheric depressions (low atmospheric pressures) are associated with strong turbulence of air and, thus, with good conditions for dispersion, while anticyclones (high pressures) correspond to air stability and, thus, breed episodes of pollution.

The dispersion of pollutants increases with the speed and turbulence of the wind, and its direction orients the plumes of smoke. The vertical temperature gradient helps ascending movement of air pollutants. However, in case of temperature inversion, pollutants are blocked in the low layers of the atmosphere, which creates episodes of pollution. The transformation of air pollutants is influenced by temperature, humidity and solar rays. Solar rays and high temperature in the summer favour the photochemical formation of O<sub>3</sub>.

## The complexity of immissions

### The main pollution cycles

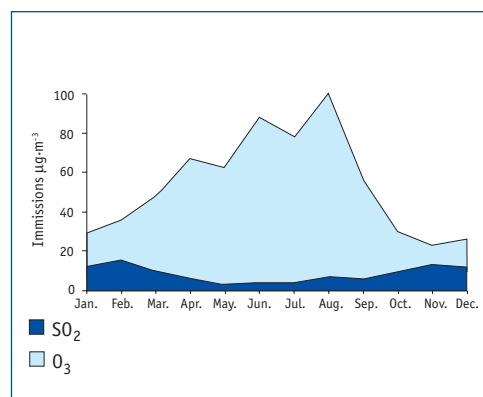
Immissions are the levels of a pollutant in the ambient atmosphere. The aerosol consists of a complex multitude of chemical compounds, not all of which have been identified. Thus, only immissions of air pollution indicators are monitored. In a given place, the immissions depend on the distance from and the height of the emission source, so that different scales of pollution can be distinguished: proximity pollution (for example, nitrogen dioxide (NO<sub>2</sub>) concentrations around a major road with high traffic density), background urban pollution (for example, NO<sub>2</sub> concentrations in a city park) and background peri-urban pollution (for example, O<sub>3</sub> concentrations even far away from urban sources of pollution). Moreover, levels of immissions result from a complex combination of fluctuations in meteorological

conditions and emissions. Thus, air pollutants have their own annual, weekly and daily cycles.

Annual cycles show month-on-month changes in the concentration of a pollutant (figure 5). Data shown in figure 5 are from ASPA (source: ASPA - 04010101-TD), the association in charge of monitoring air quality throughout the Alsace region, which includes 1.7 million inhabitants (470,000 inhabitants in the Strasbourg community), scattered over almost 900 districts and covering a surface area of 8,000 km<sup>2</sup>.

Thus, it highlights either the impact of the seasons on pollutant emissions or the direct impact of specific meteorological conditions on pollutant transformation. "Photo-oxidant" or "photochemical" air pollution is higher during the summer months, as there are favourable conditions for the production of O<sub>3</sub> (high temperatures, strong ultraviolet radiation and light winds). In contrast, "acid-particulate" air pollution (SO<sub>2</sub>, PM) is higher in the winter, because the main sources of SO<sub>2</sub> are related to electricity production (thermal power stations) and heating systems.

The weekly cycle highlights day-on-day variations in emissions, mainly linked to weekly human activities (working week/weekend). The daily cycle shows hour-on-hour changes in emissions related to human activities, and physical and chemical processes generated by the solar cycle.



**Figure 5**  
Annual cycle in SO<sub>2</sub> and O<sub>3</sub> immissions monitored in 2003 in Strasbourg (France).

decreased considerably in developed countries, as follows: in 1960, the average annual concentration of SO<sub>2</sub> was >250 µg·m<sup>-3</sup> in the Paris area; ~200 µg·m<sup>-3</sup> in 1970; just above 100 µg·m<sup>-3</sup> in 1980; and just below 50 µg·m<sup>-3</sup> in 1990. The levels of SO<sub>2</sub> were again halved between 1992 and 2003 (figure 6). Data is taken from AIRPARIF. Average annual concentrations are calculated from a constant sample for urban and peri-urban background stations for SO<sub>2</sub>, NO<sub>x</sub>, PM<sub>10</sub>, O<sub>3</sub> and benzene, and from a constant sample of traffic stations for CO. Benzene, SO<sub>2</sub>, PM<sub>10</sub>, O<sub>3</sub> and NO<sub>x</sub> in µg·m<sup>-3</sup>, and CO in 0.1 mg·m<sup>-3</sup>).

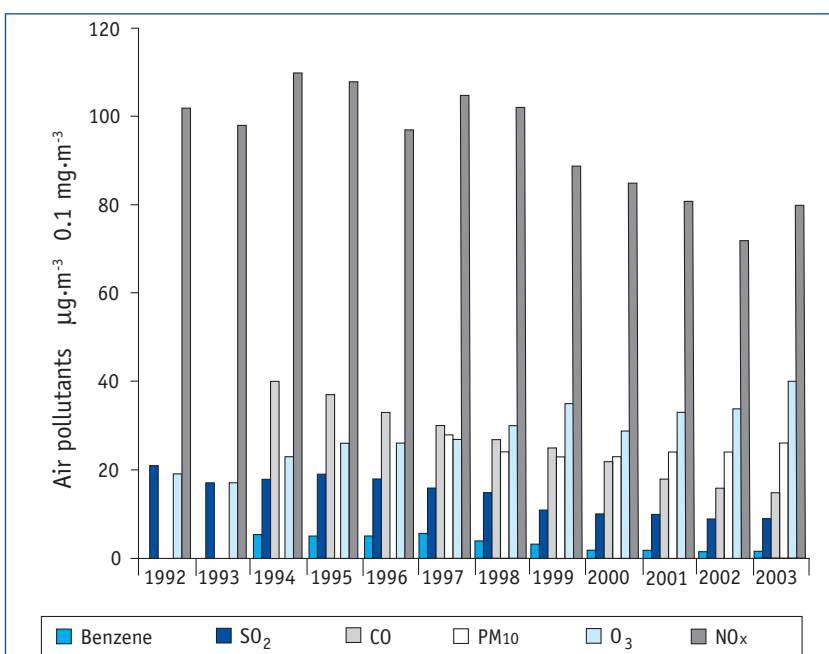
Immissions of CO have decreased regularly from 4,000 µg·m<sup>-3</sup> in 1994 to 1,500 µg·m<sup>-3</sup> in 2003. Levels of benzene were ~5 µg·m<sup>-3</sup> until 1997 and have stabilised at ~2 µg·m<sup>-3</sup> since 2000. Levels of lead have decreased considerably in Europe, thanks to the use of lead-free oil.

The evolution of NO<sub>x</sub> levels is less encouraging. NO<sub>x</sub> immissions remained almost constant from 1992 to 1998 in the Paris area, while a slight fall has been observed since 1999. Moreover, PM<sub>10</sub> levels did not show any significant change between 1997 and 2003. Unfortunately, PM<sub>2.5</sub> levels have not been heavily monitored thus far. The evolution of O<sub>3</sub> concentrations is worsening, as O<sub>3</sub> concentrations doubled between 1992 and 2003.

### Legislation and norms

The principal limit values in the ambient air, according to the European directives of April 22nd, 1999, for SO<sub>2</sub>, NO<sub>2</sub>, NO<sub>x</sub>, PM and lead, of November 16th, 2000, for benzene and CO, and of February 12th, 2002, relating to O<sub>3</sub> are provided in table 1. European directives are moving progressively towards a drastic reduction in threshold for air quality criteria.

**Figure 6**  
Average annual levels of air pollutants in the Paris area from 1992 to 2003.



## Air pollution effects

Air pollution and its effect on human health are presently being debated in both the scientific and political arenas. However, air pollution from natural sources has always existed. Plinius the Younger described, for the first time, a fatal respiratory disorder induced by natural air pollution: the patient was Plinius the Elder, who had moved to Pompei (Italy) to observe the eruption

of Mount Vesuvius in the year 73 AD and who had breathed air pollutants emitted by the volcano [8]. Even though Henry Hyde Salter linked "impure air" with asthma in his book *On Asthma: Its Pathology and Treatment*, published in London in 1860 [9], people only became aware of the health effects of air pollution in the 1950s, with the episodes of black smog in London. Indeed, air pollution caused by coal combustion for heating provoked 4,000 deaths in London in 1952 [10].

**Table 1** European air quality criteria

Pollutant	Limiting values	Warning levels
NO <sub>2</sub>	On annual average 2004: 52 $\mu\text{g}\cdot\text{m}^{-3}$ , linearly decreasing in the course of time 2010: 40 $\mu\text{g}\cdot\text{m}^{-3}$ On time average Until 2010: percentile 98 h <sup>#</sup> = 200 $\mu\text{g}\cdot\text{m}^{-3}$ 2004: percentile 99.8 h <sup>¶</sup> = 260 $\mu\text{g}\cdot\text{m}^{-3}$ , linearly decreasing 2010: percentile 99.8 h = 200 $\mu\text{g}\cdot\text{m}^{-3}$	400 $\mu\text{g}\cdot\text{m}^{-3}$ on time average over 3 hours consecutively
NO <sub>x</sub>	On annual average 30 $\mu\text{g}\cdot\text{m}^{-3}$ (protection of the vegetation)	
SO <sub>2</sub>	On annual average 20 $\mu\text{g}\cdot\text{m}^{-3}$ (for the ecosystems) On daily average Until 2005: percentile 99.2 d <sup>+</sup> = 125 $\mu\text{g}\cdot\text{m}^{-3}$ On time average 2004: percentile 99.7 h <sup>§</sup> = 380 $\mu\text{g}\cdot\text{m}^{-3}$ 2005: percentile 99.7 h = 350 $\mu\text{g}\cdot\text{m}^{-3}$	500 $\mu\text{g}\cdot\text{m}^{-3}$ on time average over 3 hours consecutively
Lead	On annual average 2004: 0.6 $\mu\text{g}\cdot\text{m}^{-3}$ 2005: 0.5 $\mu\text{g}\cdot\text{m}^{-3}$	
PM <sub>10</sub>	On annual average 2004: 41.6 $\mu\text{g}\cdot\text{m}^{-3}$ 2005: 40 $\mu\text{g}\cdot\text{m}^{-3}$ , linearly decreasing 2010: 20 $\mu\text{g}\cdot\text{m}^{-3}$ On daily average 2004: 55 $\mu\text{g}\cdot\text{m}^{-3}$ not exceeded >35 days per year 2005: 50 $\mu\text{g}\cdot\text{m}^{-3}$ not exceeded >35 days per year 2010: 50 $\mu\text{g}\cdot\text{m}^{-3}$ not exceeded >7 days per year	
CO	On average over 8 hours 2004: 12 mg·m <sup>-3</sup> 2005: 10 mg·m <sup>-3</sup>	
Benzene	On annual average Until 2005: 10 $\mu\text{g}\cdot\text{m}^{-3}$ , linearly decreasing 2010: 5 $\mu\text{g}\cdot\text{m}^{-3}$	
O <sub>3</sub>	On average over 8 hours 120 $\mu\text{g}\cdot\text{m}^{-3}$ , not exceeded >25 days per year (on average over 3 years)	240 $\mu\text{g}\cdot\text{m}^{-3}$ on time average

#: hourly value which should not be exceeded >175 hours per year; ¶: hourly value which should not be exceeded >18 hours per year; +: daily value which should not be exceeded >3 days per year; §: hourly value which should not be exceeded > 24 hours per year.



This type of black smog no longer occurs in the big cities of developed countries. However, air pollution remains a worsening problem in urban areas, where ~50% of the world's population lives and where ~400 million city inhabitants are exposed to air pollutants derived from motor vehicles. The short-term effects of short exposure to important doses of air pollutants are no longer the main concern of developed countries, as the levels of air pollutants have considerably decreased since 1960. The long-term effects of chronic exposure to low doses have become a new cause of concern. However, long-term effects of air pollution are difficult to study because of the complex determination of the exposure, the low intensity of the potential effect and the waiting period before the apparition of the potential effects. The Environmental Science Engineering Programme at the Harvard School of Public Health concluded that ~4% of the death rate in the USA can be attributed to air pollution [11]. Moreover, the cost of air pollution from traffic across three European countries has been estimated to exceed that from traffic accidents [12]. The investigation of health effects of outdoor air pollution is complicated by the fact that indoor air pollution is also noxious for human health [13].



### The notion of absorbed dose, exposure and individual susceptibility

The nature and the importance of health effects caused by air pollutants depend on three factors: the type of pollutant, the absorbed dose, and the individual susceptibility [14, 15].

The absorbed dose is the quantity of pollutant that penetrates into the organism. This dose depends on three factors.

$$\text{Absorbed dose} = \text{immissions} \times \text{duration} \times \text{pulmonary ventilation}$$

1) The concentrations (=immission) of pollutants in the air: outdoor concentrations of air pollutants are different from indoor concentrations, for example. Outdoor pollutants can also affect indoor air, although the indoor environment has its own peculiar pollution (building materials, cigarette smoke, air conditioners, photocopiers, etc.).

2) The duration of exposure: the exposure is the interaction between the individual and the environments in which he/she lives. In most industrialised countries, people spend more than 80% of their time indoors and in transport, increasing exposure to pollutants within closed walls. Thus, the absorbed dose is partly due to indoor air pollution.

3) The level of physical activity: physical effort is related to an increase in pulmonary ventilation and, thus, to an increase of the quantity of pollutants introduced into the organism by inhalation.

Even if two individuals receive the same dose of pollutants, they might experience different effects, in so far as they might have different individual susceptibilities [16]. Indeed, several populations are more vulnerable, such as children, the elderly, pregnant females and people with heart or lung disease. Furthermore, recent studies have shown that susceptibility is partly genetically regulated.

### The effects of the main air pollution indicators on health

Air pollutants can lead to health problems either directly when they penetrate the organism or indirectly by the modification of the environment. Pollutants enter the organism through three different mechanisms. 1) Inhalation: man breathes ~15 m<sup>3</sup> of air, including pollutants every day. 2) Ingestion: some air pollutants can deposit onto soil or surface water, where they are taken up by plants and ingested by animals, and are eventually introduced into the food chain. 3) Skin

contact: this type of contact is less frequent, except in case of accidental pollution or armed conflicts.

Air pollutants can cause serious health problems, including respiratory problems (asthma, irritation of the lungs, bronchitis, pneumonia, decreased resistance to respiratory infections), allergies, adverse neurological, reproductive and developmental effects, cancer, and even early

death. Several reviews have reported extensively on the effects on health.

### The effects of the main air pollution indicators on the environment

Main health and environmental effects of the common air pollutants are summarised in table 2. Some pollutants also cause certain environmental

**Table 2** Main air pollution indicators and their effects on the environment and health

<b>Pollutants</b>	<b>Health effects</b>	<b>Environmental effects</b>
<i>NO<sub>2</sub></i>	<i>It is a respiratory irritant It may worsen existing respiratory illness It may lead to bronchial hyperresponsiveness and a decrease in lung function in asthmatic subjects</i>	<i>NOx oxidises in the atmosphere to become nitric acid, a major component of acid rain It combines with VOC to form O<sub>3</sub></i>
<i>SO<sub>2</sub></i>	<i>It is a respiratory irritant It may worsen existing respiratory illness: for example, it provokes asthma attacks in asthmatic subjects It increases adults' respiratory symptoms, such as cough It alters childrens' lung function</i>	<i>It oxidises in the atmosphere to become sulphuric acid, a major component of acid rain</i>
<i>Lead</i>	<i>This metal accumulates in the body It causes brain and nervous system damage, especially in children (lead poisoning) and renal system damage</i>	
<i>PM</i>	<i>Particles effects on health depend on their size PM<sub>10</sub> causes: Nose and throat irritation Lung damage Bronchitis Risk of cardiac arrest Carcinogen effects if they carry toxic compounds Early death</i>	<i>Smoke and dust can dirty and discolour structures</i>
<i>CO</i>	<i>It binds to the oxygen-carrying site on haemoglobin, which reduces O<sub>2</sub> transport in the body At high concentrations it is very toxic, causing headaches, nausea, reduced ability to think, and even death</i>	<i>It oxidises in the atmosphere to become CO<sub>2</sub>, a greenhouse effect gas It can combine with other gases to form O<sub>3</sub></i>
<i>VOC</i>	<i>They have various effects, depending on their chemical compound They may be associated with cancer, as well as adverse neurological, reproductive and developmental effects</i>	<i>They can combine with NOx to form O<sub>3</sub></i>
<i>O<sub>3</sub></i>	<i>It may cause eye irritation It can irritate the respiratory tract It induces severe coughing, shortness of breath and lung irritation It leads to greater susceptibility to respiratory illnesses, such as bronchitis and pneumonia It exacerbates asthma attacks</i>	<i>It damages plants and trees It induces reduction of visibility</i>

**Useful web links**

[http://europa.eu.int/comm/environment/policy\\_en.htm](http://europa.eu.int/comm/environment/policy_en.htm)

The site of the European Union contains various data on the activities, institutions, documents and services of the European Union. The page above provides information about policies on environmental themes, including air (air quality, air emissions, transport and environment) and health, focusing on the interaction between health and the environment.

[www.epa.gov/ebtpages/air.html](http://www.epa.gov/ebtpages/air.html)

The page about air on the US Environmental Protection Agency site contains a lot of information about air pollutants, air pollution legal aspects and the main sources of air pollution in the USA, air pollution monitoring, as well as health effects.

conditions, such as acid rain and climate change, particularly global warming. Increases in temperature might result in a variety of impacts, including more heat-related illness, more severe weather events, such as floods and droughts and resulting damage, and an increase in cases of vector-borne and water-borne diseases, and rises in sea level.

## Conclusion

Air pollution and specifically urban air pollution remain worrying concerns. Indeed, exposure to air pollutants can lead to an increase not only in morbidity but also in mortality. Even if important

progress was made in order to reduce emissions of industrial sources, with a substantial decrease in SO<sub>2</sub> concentrations, road traffic has become the first source of emissions in urban areas, with a subsequent increase in photo-oxidant air pollution. Thus, the development of alternative fuels and engine types that can reduce emissions of air pollutants, as well as the use of public transport or bicycles for example, are necessary. Moreover, important decisions need to be taken by governments to reduce air pollution and its hazardous effects on health and the environment. New studies on the long-term effects of low doses of air pollutants are needed, including important partnerships between epidemiologists, toxicologists, metrologists, chemists, physicists and biologists.

### Educational questions

- Name the five main stages in the cycle of air pollution.
- Name six air pollution indicators.
- What is the major source of air pollution in urban areas?  
 industry     road transport     solvent use     domestic heating     other
- Name three factors other than emissions (type, intensity, distance, height) that determine levels of immissions.
- Describe the evolution of immissions of the following air pollutants over the last 10 years in big cities.
 

SO <sub>2</sub>	<input type="checkbox"/> increase	<input type="checkbox"/> reduction	<input type="checkbox"/> stagnation
CO	<input type="checkbox"/> increase	<input type="checkbox"/> reduction	<input type="checkbox"/> stagnation
Lead	<input type="checkbox"/> increase	<input type="checkbox"/> reduction	<input type="checkbox"/> stagnation
Benzene	<input type="checkbox"/> increase	<input type="checkbox"/> reduction	<input type="checkbox"/> stagnation
NO <sub>x</sub>	<input type="checkbox"/> increase	<input type="checkbox"/> reduction	<input type="checkbox"/> stagnation
PM <sub>10</sub>	<input type="checkbox"/> increase	<input type="checkbox"/> reduction	<input type="checkbox"/> stagnation
O <sub>3</sub>	<input type="checkbox"/> increase	<input type="checkbox"/> reduction	<input type="checkbox"/> stagnation
- Name the three factors that determine the nature and the importance of the health effects of air pollution.
- What are the three factors that determine the absorbed dose?

## References

1. Delon S. *La Pollution de l'air: sources, effets, prévention* [Air pollution: sources, effects, prevention]. Paris, APPA (Association pour la Prévention de la Pollution Atmosphérique), 1998.
2. HEI perspective 2002. *Understanding the health effects of components of the particulate matter mix: progress and next steps*. [www.healtheffects.org](http://www.healtheffects.org). Date last accessed: October 26, 2004.
3. ASPA. *The AIR*. [www.atmo-alsace.net](http://www.atmo-alsace.net). Date last accessed: June 18, 2004.
4. AIRPARIF. *Pollutants*. [www.airparif.asso.fr/english/polluants/default.htm](http://www.airparif.asso.fr/english/polluants/default.htm). Date last accessed: June 25, 2004.
5. *Atmo Champagne-Ardenne. Pollutants measured*. [www.atmo-ca.asso.fr/en/home\\_polluants.html](http://www.atmo-ca.asso.fr/en/home_polluants.html). Date last accessed: June 15, 2004.
6. Serveau L, Allemand N, Chang JP, et al. *Inventaire des émissions de polluants atmosphériques en France – séries sectorielles et analyses étendues. Format Secten. Rapport d'Inventaire National* [Emission inventories of air pollutants in France in SECTEN format]. Paris, Centre Interprofessionnel Technique d'Etudes de la Pollution Atmosphérique (CITEPA), 2004.
7. Festy B. *La pollution atmosphérique urbaine: sources, polluants et évolution*. [Urban atmospheric pollution: sources, pollutants and evolution]. *Bull Acad Natl Med* 1997; 181: 461–474.
8. Plinius the Younger. *Letter to Tacitus*. Letter VI.16. 105 AD. Rome, Italy. [www.amherst.edu/~classics/class36/ancsrc/01.html](http://www.amherst.edu/~classics/class36/ancsrc/01.html)
9. Salter HH. *On asthma: its pathology and treatment*. 2nd Edn. London, Churchill Livingstone, 1868.
10. Logan WP. *Mortality in the London fog incident, 1952*. *Lancet* 1953; 1: 336–338.
11. Dockery DW, Pope CA 3rd, Xu X, et al. *An association between air pollution and mortality in six US cities*. *N Engl J Med* 1993; 329: 1753–1759.
12. Kunzli N, Kaiser R, Medina S, et al. *Public-health impact of outdoor and traffic-related air pollution: a European assessment*. *Lancet* 2000; 356: 795–801.
13. Viegi G, Annesi-Maesano I. *Indoor air pollution and airway disease*. *Int J Tuberc Lung Dis* 2004; (in press).
14. APPA (Association pour la Prévention de la Pollution Atmosphérique). *Atmosphere atmosph'air: dossier 7 "Et ma santé" ["And my health" file 7]*. [www.appa-ds.com](http://www.appa-ds.com). Date last accessed: June 30, 2004.
15. Quénel P. *Pollution atmosphérique et santé* [Air pollution and health]. [www.allergonet.com/Articles/Article98-99LPQuenel.asp](http://www.allergonet.com/Articles/Article98-99LPQuenel.asp). Date last accessed: June 30, 2004.
16. Annesi-Maesano I, Agabiti N, Pistelli R, Coulliot R, Forastiere F. *Subpopulations at increased risk of adverse health outcomes from air pollution*. *Eur Respir J* 2003; 21: Suppl. 40, 57s–63s.

## Suggested further reading

D'Amato G, Holgate ST. *The impact of air pollution on respiratory health*. *Eur Respir Mon* 2002; 21: 1–282.

*A series of articles on the relationship between air pollution and respiratory health in various areas: epidemiology, toxicology, immunology, cell and molecular biology, and public health.*

Künzli N, Kaiser R, Medina S, et al. *Public-health impact of outdoor and traffic-related air pollution: a European assessment*. *Lancet* 2000; 356: 795–801.

*An estimation of the impact of outdoor (total) and traffic-related air pollution on public health in Austria, France, and Switzerland. Attributable cases of morbidity and mortality were calculated.*

*Respiratory epidemiology*. In: Annesi-Maesano I, Gulsvick A, Viegi G, eds. *Eur Respir Mon* 2000; 15: 1–391.

*Epidemiological methods for the study of health effects of outdoor and indoor air pollution with two detailed chapters on the topics.*

## Suggested answers

1. **Emission** of air pollutants from human-made or natural sources is the first stage in the cycle of air pollution. Both **dispersion** and **transformation** of air pollutants are the following stages. **Immission** (=concentration in the ambient air) is the fourth stage, which results from the three previous stages. The last stage consists of **deposition** of air pollutants (e.g. acid rain).
2. It is not possible to monitor all the pollutants in the atmosphere. **SO<sub>2</sub>**, **NO<sub>x</sub>**, **PM**, **CO**, **VOC** (benzene, for example) and **O<sub>3</sub>** are the main air pollution indicators that are monitored in Europe because of their detrimental effects on health. Several toxic metals, such as lead, can also be considered as air pollution indicators, even if levels of lead have decreased considerably. Moreover, emissions of greenhouse effect gases, such as CO<sub>2</sub> or CH<sub>4</sub>, are also monitored because of their detrimental effects on the environment.
3. Globally, **road transport** is the major source of air pollution in urban areas. It is the first source of emissions of CO, PM and NO<sub>x</sub> and the second source of NMVOC.
4. **Atmospheric pressure, wind and temperature.**
5. SO<sub>2</sub>: continuation of the **reduction** that had begun 40 years ago.  
CO: **reduction**.  
Lead: very important **reduction**, thanks to lead-free oil.  
Benzene: important **reduction** since 1998.  
NO<sub>x</sub>: **very slight reduction** since 1998. The concentrations of NO<sub>x</sub> in big cities often remained above recommended values.  
PM<sub>10</sub>: **stagnation** because of the increased proportion of diesel vehicles.  
O<sub>3</sub>: worrying **increase**.
6. The **type of pollutants**, the **absorbed dose** and the **individual susceptibility**.
7. The levels of **immissions**, the duration of **exposure** and **pulmonary ventilation**.