# The unsustainable heaviness of air

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Commons include air, sky, light
Res communes omnium (Giuseppe De Nittis, 1868)

## Abstract

### Debate on air pollution

Air quality and tolerable levels of pollution might seem debatable concepts when they replace the absolute concept of air, good in itself, to admit the right of industries and consumers to pollute. The current view is that pollution is an inevitable effect of growth and growth is the imperative for profit. By externalising social and environmental costs, industry can maximize profit. Everyone including future generations is paying by allowing enterprises to have this freedom. Resource management, introduced to reconcile pollution with sustainability is a false concept when its operational meaning is dictated by the bottom line principle. As a result pollution becomes the partner of the free market ideology. Since the 1950s when the great acceleration took off, human activities have reached the tipping point in terms of extraction, production and consumption. Air pollution is an effect of this growth and its impact on workers' health has raised strong concerns.

### Air pollution and the susceptibility of workers

Air pollution exerts a different impact on different populations and factors contributing to these variations can be explained by susceptibility. Workers are forced to experience inferior respiratory conditions both at work, due to the indoor air pollution and during their free time thanks to the outdoor pollution. Air pollution aggravates risks accumulated by some categories of workers (vulnerability vector) seriously threatening their health. As reported by the ILO, an estimated 2 billion workers breathe in dangerous levels of air. Occupational epidemiology provides statistics on the impact of air pollution on workers' diseases and death therefore raising the concern about the relation between air pollution and public health. Exposure (concentration, dose and inhalation time) is studied to mitigate the risk of air pollution, but the interaction effect (chemical reaction among multiple pollutants) impedes evidence on the true effect on workers' health.

The problem: the transformation of air composition

Owing to the growth and related increase in emissions in the atmosphere, the composition of air is changing and the marginal part of it (78% Nitrogen, 21% Oxygen, 1% Traces gases) plays a decisive role in worsening workers' health. Conventional primary pollutants contribute the largest volume of air quality degradation: Sulphur compounds ($SO_2$), Nitrogen compounds ($NO_x$), Carbon oxides ($CO_2$, co), Metals (Lead, Mercury), Halogens (CFCs), particulate material, volatile organic compounds (VOCs). Indoor air pollutants, including formaldehyde, asbestos, toxic organic chemicals, randon, tobacco smoke, are considered unconventional pollutants. In addition secondary pollutants, not directly emitted as such but formed when primary pollutants react in the atmosphere, include ozone which is formed when hydrocarbons (HC) and nitrogen oxides ($NO_x$) combine in the presence of sunlight. Toxicology science, Occupational Epidemiology and WHO provide evidence of the impact of these pollutants on human health. Effects vary from acute (reversible) and chronic (irreversible) illness and diseases. Each pollutant has its own effect. For instance, particulate matter affects the respiratory systems and genetic structure leading to death. Sulphur dioxide inhibits the respiratory system as well adding cardiovascular diseases and lung cancer. Carbon monoxide interferes with the blood's ability to provide an adequate supply of oxygen to body tissue, causing brain damage, angina pectoris, and foetal abnormalities. Nitrogen dioxide affects the respiratory systems, lowering resistance to infection. Lead affects the blood, nervous and renal system. Ozone impacts on lung inflammation, breast cancer. Pollutants may last even as long as 30 years in the atmosphere and they migrate around the world at heights of up to 17 kilometres. Human breathing which needs 11 $m^3$ every 24 hours, is exposed to both air pollutants and secondary pollutants which cause mutagenic effects (mutagens). Epigenetic science has proved that air pollution changes the human genetic structure (DNA) leading to death.

The solution: the prevention strategy

The aim of air pollution prevention is to avoid and reduce the quantity and the hazardous character of pollutants. Literature on prevention includes three areas following the cycle of pollutants: sources, transportation and receptors. At source, emission ratios and type of pollutants are studied within other physical variables such as height, temperature, pressure and the speed of exit. The transportation issue includes wind speed, moisture, temperature, physical transportation and chemical reactions, atmospheric chemistry and physics. Receptors, in their turn, include sea, earth, humans, animals, monuments, buildings and the atmospheric itself. While air pollution prevention cannot be applied in the transportation phase, prevention at source and at receptors is applied.

The European Union is the most influential actor on the international scene regarding prevention policy even if its legal framework is not binding for member states. The Directive on Industrial Emissions replaces previous legislation and represents a sound legal framework on prevention policy, covering definitions, general principles and prevention obligations, best available technologies, emission limit values, installations requirements, environmental inspections, controls of emissions and monitoring and special provisions for installations and activities using organic solvents. Technical issues are presented in the Annexes. The decision to designate 2013 as the Year of Air reflects the concern about the impact of pollutants on human health. The European Environment Agency plays an important role in prevention policy. Air Quality in Europe Reports provide data on sources and effects of Particulate Matter, Ozone, Nitrogen Dioxide, Sulphur Dioxide, carbon Monoxide, heavy Metals and Benzene.

Air Pollution Prevention includes the adoption of green technologies, prevention programmes in enterprises and integrated approaches (prevention and recycling). Cooperation among science, industry and educational institutions is a key determinant in achieving results from prevention policy. Progress on sustainability science is also needed so as to overcome two obstacles impeding the comprehensive view for air pollution prevention: the complexity of the problems and the concomitant specialisation of science that seeks to address problems. Due to the "mobility" of air pollution sustainability science and policy makers should provide uniform solutions to different (even if global) problems. This overarching strategy should overcome the compartmentalization of disciplines and be based on a trans-disciplinary approach.

Collective action is also required following the comprehensive perspective on sustainability and air pollution prevention. The collective action points out that a single action has a limited impact. Without the orchestration towards a comprehensive prevention policy all activities by numerous actors have a marginal effect. By strengthening a network of networks, sustainability knowledge is shared, learning processes become mutual, skills and resources are used in complementary way and the innovation toward air pollution prevention is breathed collectively. Educational institutions must play the key role in achieving this collective action.

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## Introduction

Air pollution is the introduction of harmful substances into the environment. Air Pollution has been a public health problem since the discovery of fire. The term Pollution stems from the Latin polluere alteration or defilement and was first coined by John Spengler in 1983 (Spengler, 1983). Seneca noted the "heavy air of Rome in 61 A.D while King Edward in 1272 banned the burning of sea-coal. The origin of modern air pollution problems can be traced to eighteenth century England and the birth of the Industrial Revolution. The history of air pollution includes disasters and related policies to prevent them. (United States Environmental Protection Agency, 2003). In 1940 the air pollution problem, defined as "smog" forced regulators to act in USA. The episode of London fog in 1952, when over 4.000 people died might be the symbol of air pollution's anthropocene effect - terms coined by Eugene Stoermer and used to mark the evidence and extent of the impact of human activities on the Ecosystem starting from the 1950s. The second half of the 20th century is unique in history since many human activities reached take off points and sharply accelerated towards the limits reported at the end of the century relating to population growth, CO2 concentration, N2O concentration, CH4 concentration, water use, fertiliser consumption, urban population, ocean ecosystem depletion, motor vehicles, telephones, tourism, etc.

"The air we breathe contains emissions from motor vehicles, industry, heating and commercial sources, as well as tobacco smoke and household fuels" (WHO, 2005). This United Nations official sentence legitimates the concept of air quality and the intrinsic right of industries to pollute.

The current view is that pollution is the inevitable effect of profit and profit is the imperative for growth. By externalizing social and environmental costs, industry can maximize profit. Everybody and even future generations is paying for this freedom of enterprises.

Policy decision makers try to reconcile pollution as a "natural effect" of growth introducing resource management and legislation to mitigate the pollution impact on human health and the environment. Resource management in itself is a false concept when its operational meaning is dictated by the imperative of the bottom line. As a result, pollution becomes a natural partner of the free market ideology. Legal systems, based on this framework, foresee a crime when a person poisons another but not when the culprit is the intermediary pollution.

Science studies emissions from natural sources such as volcanoes or forest fires and related air composition and equates natural pollutants with pollutants coming from human action. A solution is seen in the legislation that makes the polluter pay for pollution and the payment must be high enough to act as a deterrent. But, to date, this principle has failed as a deterrent.

Epidemiology takes for granted the chain emissions-transportation-receptors and measures the tolerable levels of impact.

The tolerable level of pollution confirms the right of industries to pollute replacing the concept of air with air quality, therefore eliminating the absolute concept of air, good in itself. It is said that exposure to air pollutants is largely beyond individuals' control and that it requires action by public authorities at regional, national and international levels. Mitigation and adaptation are concepts used by all UN Agencies, therefore perpetuating the logical framework based on the growth-pollution relationship.

While the hazardous properties of many common pollutants are still under intensive research, evidence-based policies demonstrate that decisive health protection is possible and effective. For example, phasing out leaded petrol decreases blood lead levels in children and reduces their risk of impaired neurobiological development. Controlling air pollution, both indoor and outdoor, can significantly prevent diseases. But this is not enough. A different strategy is needed.

This different strategy and counter arguments are supported by international documents relating to human and environmental rights such as the 1972 Stockholm Declaration, UN Resolution 37/ 7, 1982, the World Charter of Nature and human development, the Rio Declaration of Human Rights (UNCED, 1992).
How can we guarantee any of the human rights and freedom such as life if we poison our air? Breathable air and the amount of 11 m3 required for breathing every 24 hours are essential to support all life, including that of the polluters.
In this approach air is treated as natural heritage of humankind and the misleading effect of the air quality concept is highlighted.
The tragedy of the commons is a concept developed by Hardin (Hardin, 1968) and states that when a commons or common natural resource like air is exploited disproportionally by one or more persons at the expense of all others, it is tragic. In a sense, Air pollution is exploiting air.
Air pollution is an example of the problem when a commons is privately rather than publicly owned therefore creating a fundamental inequity or anti-commons situation. When an industry is allowed to pollute until a tolerable level is the tragedy of the commons.

This document highlights the air issue, in the year of air, so as to understand sustainable conditions and related actions to be taken by science, policy makers and educators.
Several misleading concepts have to be overcome and new strategic prevention has to be adopted. A new scientific approach following the ecology realm and not the free market ideology is also needed.
A communication policy is furthermore needed to convince people that air is not far from daily thoughts, it is visible, heavy and material especially when its particulate matter causes neurobiological changes leading to premature death.

Linking science, policy and the public is the aim of the European Environment Agency publications where links between air pollution and death or illness are documented.
A further publication acquires stronger relevance in the year of air: the ILO report on Worker Safety and Health, issued on the international day of Safety and Health at Work (28 April).
EU and ILO reports show how important the air is for the working environment and the interdependency between air pollution and a healthy workplace. What follows takes the findings of mentioned reports with the aim to improve the preventive strategy towards air as the "Commons". The composition of air has a dramatic impact on our health and well-being in terms of respiratory diseases and genetic modification. Air pollution damages forests, waters, the acidity of the soils and corrodes buildings. Climate change is affected by pollution as well, aggravating the human condition through related effects on human security and health.

The vulnerability of workers due to the accumulation of polluted air inhaled both in the workplace and during free time is the focus of the following sections.
The aim is to highlight determinants of air composition, related effects on health and feasible solutions to prevent pollution at large.
Without detailing specific sectors, such as the chemical sector or specific tasks like those operating in hazardous indoor plants, the purpose is to recall salient pollutants involving the whole population therefore aggravating the poor health conditions of those already vulnerable.

This paper is organised in a somewhat unconventional manner since the emphasis is on workers' health rather than air pollution in itself. This is why the opening sections are dedicated to susceptibility and exposure. The following section discuss air pollution and its effect on workers' health. The final part outlines air pollution prevention strategy recalling the European Union's policy. The last section stresses the need for education on sustainability science.

## 1. The concept of susceptibility

It is worth beginning by highlighting the different reactions of workers to air pollution.
Since individuals respond differently to exposure to air pollution, susceptibility explains factors contributing to these variations (WHO, 2005). The concept of susceptibility explains how one is discriminated even in every breath he or she takes. Workers must face poorer breathing conditions both at work, due to the indoor air pollution and during their free time, thanks to the outdoor air pollution. Work environments are obviously not all the same and workers closer to industrial process experience poorer quality breathing compared with colleagues working in managerial centres. Hence, it is worth understanding, monitoring and preventing the negative impact of air pollution on vulnerable workers. Vulnerability refers to the inability to withstand the effects of a hostile condition. When some risks are frequently

accumulated by certain categories of workers, a "vulnerability vector" is determined with the result that the health of these workers is endangered. (F. Eyraud, 2007). In particular, a clearer understanding of the individual characteristics which increase the health risks of air pollution goes hand in hand with reducing risks for the more susceptible and prevention mechanisms.

Susceptibility refers to an altered degree of individual responsiveness. In considering the likelihood of an adverse response to an inhaled pollutant, the degree of exposure is considered in conjunction with individual characteristics. The relationship between exposure and response may take different forms, depending on the mechanism by which the pollutant causes illness or disease. In general, it is accepted that increased exposure leads to a consequent increase in risk.

Multiple factors influence susceptibility. Some factors include inherent individual characteristics (e.g. sex, age) and exposure to other agents that also have adverse effects on the same target organ (e.g. cigarette smoke or asbestos). This interaction between secondary factors, such as cigarette smoke, increases the risk from air pollution.

1.2 Socio-economic factors

The main factor influencing susceptibility is economic status.
Surveys on susceptibility have shown the close relationship between air pollution health effects and socioeconomic status. Some studies suggest that residents of economically deprived inner cities are at greater risk of mortality and morbidity. It is acknowledged that a lower socioeconomic status is associated with an increased level of exposure and with behaviour, lifestyle, malnutrition, and hygiene conditions predisposed to unhealthy status. (M.S. O'Neill, 2003). It is undeniable that people with lower incomes are more likely to live in polluted major cities and near busy roads, industrial plants or other pollutant sources.
Type 2 diabetes, recognized as a major risk modifier for PM health effects is more common among adult inner city residents (J. F. Bach, 2002).

1.3 Individual health

A second cluster of factors refers to precarious health status.
Laboratory exposure studies suggest that people with asthma or coronary and respiratory diseases experience a particularly high rate of mortality. (P. Brimblecombe, 1987). People suffering from these same diseases are more vulnerable to the adverse effects from exposure to sulphur dioxide and carbon monoxide, even at lower concentrations.

## 1.4 Lifestyle

A third group of factors coincides with lifestyle. Aspects of lifestyle, in fact, aggravate the risk of an adverse effect from inhaled pollutants. Alcohol, tobacco and illegal drugs impair defence mechanisms and induce chronic inflammation and permanent structural damage in the brain and other organs. The combined effect of lifestyle and air pollutants is classified by WHO as additive or synergistic. The adverse effect is multiplied by increasing the "dose" of pollutants delivered by multiple sources or amplified by catalyzing the chemical process occurring between two or more different pollutants. When pollutants from air interact with pollutants linked to drugs, such as cocaine or heroine, the metabolic system changes, leading to genetic disjunctions. Additive and synergistic effects are concomitant when the pollutants of the working environment are added to pollutants deriving from workers' lifestyle. In some cases ultra-fine particles react with the genetic structure (nitrogenous base) causing cancer.

## 1.5 Genetic factors

Technological advances in molecular biology have increased the understanding of the pollutant mechanism, specific genes and the genetic susceptibility factors. Candidate genes include tumour necrosis factor α, inflammatory cytokines, the toll-like receptors and antioxidants systems. Another candidate genes most implicated in air pollution responses is glutathione S-transferase which is an important enzyme in the glutathione pathway for protection against oxidant injury as reported by recent epidemiology (D. Peden, 2005). This enzyme, present in 40% of the United States population, has a null allele with no protein expression that reduces antioxidant protection. These are some examples of increasing susceptibility due to genetic interaction between air pollution and genetic structure. What is worth noting refers to the polymorphism in drug metabolizing enzymes and cell mutation due to the reaction with the chemical component of air pollutants (K. Vahakangas, 2003).

## 1.6 Demographic age structure

Demographics represent a further factor. Difference in population age structure or the living area influences the proportion of susceptible individuals. In China, for example, people 65 years of age will outnumber those under 15 by 2050, therefore increasing the burden of chronic diseases brought by air pollution. By 2030 the urban Chinese population will overtake the rural population, thereby increasing the exposure to risk factors in the urban environment, due to new city dwellers and related additional sources of pollution (Health Effects Institute, 2004).

## 1.7 Clean water and sanitation

In poor countries or in deprived areas in more industrialized countries (US and Europe), the traditional risk factors, such as the indoor air pollution from solid fuel use or limited access to clean water and sanitation, are compounded by the modern risk factors such as tobacco smoking, referred to as “healthy risk overlap”. The comparison between industrial and poor countries shows the different susceptibility reported by the WHO. While HIV (9%), lower respiratory infections (8,2%), diarrhoeal diseases (6,3%), childhood cluster diseases (5%) are disease categories reported in poor countries, ischemic heart disease (9,4%), uni-polar depressive disorders (7,2%), cerebral-vascular disease (6%), alcohol and drug disorders (3,5%) are categories reported in Industrialized countries (WHO, 2002).

## 1.8 Occupational diseases and air pollutants

On the World Day for Safety and Health (28 April) ILO presents data on occupational diseases. An occupational disease is a disease contracted as a result of exposure to risk factors arising from work. An estimated 2 billion workers breathe dangerous levels of air, 160 million workers suffer from related diseases and there are an estimated 270 million fatal and non-fatal work related accidents per year. An estimated 2.5 million workers die each year from work-related diseases.

There are not statistics on the impact of air pollution on work-related accidents. Notwithstanding this, sound concerns have been expressed regarding relationships between air pollution and work-related accidents (mutagens)
Millions of workers continue to be at risk of pneumoconiosis, especially silicosis, coal-workers’ pneumoconiosis and asbestos-related diseases due to widespread exposures to particulate matter (PM) emitted by construction and manufacturing processes. Their associated illnesses, such as chronic obstructive pulmonary disease, cause permanent disability or premature death. (ILO, 2013). Though some traditional risks (like asbestos) have declined due to improved safety, technological advances and better regulation, they continue to take an unacceptably heavy toll on workers’ health. In parallel, new forms of occupational disease are increasing without adequate preventive, protective and control measures. Emerging risks include poor air composition and its interaction with socio-economics conditions, with particular emphasis in rural areas, small and medium sized companies and in the informal economy. According to ILO statistics, the issue of air pollution should be included in the Occupational Safety and Health Convention (Nr 155/1981), Occupational Health Service Convention (161/1985) and the Promotional Framework for Occupational Safety and Health Convention (187/2006). Yet, the relationship between air pollution and health effects should go beyond the EU legal framework and be included as a permanent theme in the EU policy debate.

## 2. Exposure

### 2.1 General framework

Human exposure is determined by the amount of air pollution in the environments (microenvironments) where people spend their time and by the amount of time spent there. Space, time and pollutants determine the "microenvironments". (W.R. Ott, 1982). According to these criteria, the world is classified into four microenvironments as outlined in the following scheme:

Fig 1 Classification of exposure

| | Industrialised Countries | | Non Industrialised Countries | |
|---|---|---|---|---|
| | Rural | Urban | Rural | Urban |
| Indoor | | | | |
| Outdoor | | | | |

This classification can be applied both to industrialised and non-industrialised countries leading to 8 microenvironments.
Human exposure is when a person comes into contact with a pollutant of a certain concentration during a certain period of time. Cumulative exposure is the most common indicator to measure exposure used in occupational epidemiology (T.J. Smith, 1992). It is the result of concentration (or intensity) multiplied by duration. Its utility in describing exposure-effects relationships is based on several interlocking assumptions about processes related exposure to tissue dose and tissue dose to adverse effects.

### 2.2 Concentration and dose

Exposure is distinguished from concentration, the quantitative amount of a pollutant within a given environmental, and from the dose, the amount of pollution actually entering the respiratory system. The dose includes a wide range of factors specific to the pollutant, such as solubility or pattern of deposition in the lungs, or physiological factors (personal level of activity, skin condition, health status, etc). Exposure studies are focused on respiratory and interrelated cardiovascular effects following inhalation. Needless to say information on people's time is used in conjunction with data on air concentration in the related microenvironments. The most important microenvironments for air pollution exposure are those where people spend the majority of their time and those likely to contain the highest concentration of air pollutants, including workplaces, home and traffic routes.

### 2.3 The assessment of exposure

Exposure assessment is used by Health institutions and scientists to estimate people's risk caused by air pollutants. In general, a four-step process is adopted so as to identify pollutants in the air (phase 1), to estimate the amounts of these pollutants released from different sources (phase 2), and related concentration (phase 3), to provide estimates of the number of people who breathe air containing reported pollutants (phase 4) (US EPA, 1991).
Exposure assessment takes into account the appropriate time average since a large proportion of daily exposure occurs in only a few hours. If a heavy metal is observed, a simple calculation of long-term average is provided by adding the total personal exposure averaged over each micro-environment. On the other hand, sulphur dioxide requires just a few minutes for the exposure calculation. Exposure effectiveness is defined as the fraction of pollutant that actually enters a person's breathing zone: the amount of material actually inhaled, ingested or absorbed by an individual. The potential for a pollutant to affect human health is determined by its exposure effectiveness.

### 2.4 Cigarettes as a key pollutant

Studies suggest that although benzene emission from cigarette smoke is only a small fraction of the emissions from vehicles, cigarettes can have an intake fraction up to a few hundred times more than outdoor emissions (D.H. Bennett, 2002). Since people spend most of their time indoors, most of the exposure to pollution of outdoor origin takes place indoors, where exposure can be modified by the building and its equipment such as air conditioning.
The issue is particularly aggravated when the indoor area in question is an industrial plant. Here, after the emission takes place, inert pollutants such as carbon monoxide disperse but for chemically reactive pollutants such as nitric oxide, a higher concentration indoor and outdoor develops.

### 2.5 Workers affected by primary and secondary pollutants.

The formation of secondary pollutants, in contrast, develops as a large-scale phenomenon with a uniform spatial distribution. As a result, workers who are vulnerable, suffer double effect: the spatial distribution of secondary pollutants and the concentration gradient related to the first pollutants. Particulate matter has a different spatial variability. Fine particles have a small spatial variability while ultra-fine and coarse particles have a much wider spatial variability. Specific components such as elemental carbon (diesel soot) and nitrogen dioxide concentrations show quite strong spatial variability owing to the distribution of local emission sources (vehicles). On the contrary, the spatial variability of ozone is reported very low across larger areas. The interaction of multiple pollutants between outdoors and industrial plants depends on the so-called penetration coefficient, the ventilation rate and the decay rate (W.E. Wilson, 2000; L. Wallace, cit).

## 2.6 The Interaction effect

The problem of interaction for multiple pollutants requires data on differences between measured and actual pollution levels for each pollutant and information about differences in correlations across pollutants (J. Schwartz, 2004). Particles flying in outdoor air penetrate to indoor air. Ozone, for example is a highly reactive component and reacts quickly with surfaces when penetrating indoors developing further chemical reactions. Ozone concentrations are generally high during sunny weather, conditions under which windows are open. The same applies for nitrogen dioxide and sulphur dioxide concentration of which is reported high notwithstanding the absence of sources in the indoor air. Workers in non-decent working conditions, particularly those working in less protected structures have less control over their respiratory system. The flux of air pollution penetrating industrial plants increases with ventilation rate which is higher when it is windier outside, when the temperature difference between indoor and outdoor air is higher and when the windows are open for a longer period. Several epidemiological studies provide evidence of different levels of toxic concentration in different outdoor-indoor interactions. (J.A. Sarnat, 2000; D.T Mage, 2001).

## 2.7 Knowledge about health effects yet to be implemented

It remains unclear whether the observed association between nitrogen dioxide and health is due to the nitrogen dioxide itself or whether nitrogen dioxide is an indicator of other correlated pollutants, such as ultra-fine particles emitted by other outdoor sources. For acute effect it would be interesting to investigate whether the exposure of workers followed from day to day varies with the respective day-to-day variation in outdoor air pollution. Although the association between indoor and outdoor air pollution has shown variations from worker to worker on a company population level, this correlation is considered to be sufficiently high to justify the use of outdoor concentration as a measure of exposure. It is worth noting that for pollutants with low effective penetration from outdoor to indoor environments such as ozone, significant correlations have been found only for outdoor workers or during warm weather (M.S. O’Neill, 2003). Epidemiological studies on the relationship between indoor-outdoor air pollution has been conducted in Europe and North America and little knowledge is available in other parts of the worlds. Studies also report different impacts for susceptible workers, such as roadside vending resulting in obviously higher exposure.

## 2.8 Air Pollution Forecasts

Levels of air pollution are measured by Air Quality Indexes. For example in US the Air Quality Index is adopted while in UK the Daily Air Quality Index (DAQI) is used. The air quality indices indicate how clean or unhealthy the air is and the associated health effects. Therefore, these indices focus on health effects one can experience within a few hours or days after breathing unhealthy air and are calculated depending on the air pollutants chosen. For example in US, ground level ozone, particle pollution, carbon monoxide and sulphur dioxide are measured, while in UK the DAQI is determined by the highest concentration of fine pollutants: Nitrogen Dioxide, Sulphur Dioxide, Ozone, Particulate Matter (PM 2.5 and PM 10). These tools measure air pollutants concentration but provide no information about individual reaction to air pollutants, which could be different and worse from the index's advice. They provide health advice in the form of recommended actions to be taken, according to the level of air pollution. In general, air pollution indices are numbered (1-10 UK or 1-500 US) and accompanied by a colour showing the related risk which can be Low, Moderate, High or Very High. According to the Air Pollution Forecast, one can take simple actions to reduce one's own exposure to unhealthy air by avoiding prolonged (outdoor activity done intermittently for several hours) or heavy (outdoor activity causing to breathe hard) exertion. Regrettably, for some workers' categories, reducing working activity might be impossible.

# 3. Sources of air pollution

## 3.1 Definitions

Air pollution is defined as the existence of certain pollutants in the atmosphere at levels that adversely affect (European Environment Agency, 2013):

- human health
- environment
- cultural heritage (buildings, monuments and materials).

In its turn, the definition of pollutants is the following (Mukesh Sharma, 2008):
Presence of any substance, in some concentration, in the atmosphere that may or may tend to be injurious to human, plants, property and the atmosphere itself. This substance is called a pollutant.
The different between the two definitions refers to the impact on the atmosphere itself. This is quite important since pollutants originate chemical reactions in the atmosphere which are difficult to measure.
Air pollutants come from man-made sources and natural phenomena such as volcanic eruptions, forest fires or sand storms. Pollutants consist of dust particles travelling in the atmosphere due to winds and clouds and taking part in chemical reactions.

## 3.2 Air composition

The air includes solid, liquid and gaseous mass and assumes different density and different chemical composition depending on the altitude, pressure and temperature.
While the liquid part of air (vapour) varies depending on weather conditions, its main part, the gaseous one, contains 78% of Nitrogen (N2), 21% of Oxygen (O2) and 1% of other gases called trace gases (EEA, 2012).
Trace gases include:
Argon (Ar), Carbon dioxide (CO2), Neon (Ne), Helium (He), Kryptom (Ke), Xenon (Xe), Hydrogen (H2), Nitrous oxide (N2O), Ozone (O3), Methane (CH4 ), Sulphur dioxide (SO2 ), Nitrogen dioxide (NO2), Ammonia (NH3 ), Carbon monoxide (CO ), Iodine (I2 ), Benzene (C6H6). Primary pollutants include Sulphur Oxides (SOx), Nitrogen Oxides (NOx), Carbon Monoxide CO), Particulates, Metals (mercury and lead), Chlorofluorocarbons (CFCs), Ammonia and Volatile Organic Compounds (VOCs). Secondary Pollutants include Ground Level Ozone (O3), Nitrates and Particulates.
Thousands of other solid particles, including soot and metals influence the air composition of the atmosphere up to an altitude of 17 kilometres.

## 3.3 Volatile Organic Compounds

According to US Environmental Protection Agency (EPA, 2012) Volatile organic compounds (VOCs) are gases emitted from certain solids or liquids. VOCs include a variety of chemicals and are consistently higher indoors (up to ten times higher) than outdoors. VOCs are emitted by a wide array of products numbering in the thousands including paints and lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, office equipment such as copiers and printers, correction fluids and carbonless copy paper, graphics and craft materials including glues and adhesives, permanent markers, and photographic solutions. Organic chemicals are widely used as ingredients in household products releasing organic compounds while using them, and, to some degree, when they are stored.
EPA found levels of about a dozen common organic pollutants to be 2 to 5 times higher inside the home than outside, regardless of whether the homes were located in rural or highly industrial areas. EPA's studies indicated that while people are using products containing organic chemicals, they expose themselves and others to very high pollutant levels, and elevated concentrations can persist in the air long after the activity is completed. Chemical components of paints are solvent (Ethyl acetate and acetone) while cleaning products and refrigerants emit Chlorofluorocarbons. Benzene is a chemical found in environmental tobacco smoke and methylene chloride is in adhesive removers and aerosol sprays. When absorbed in the human body, methylene chloride is converted into carbon monoxide. Perchloroethylene is another volatile organic compound emitted during dry cleaning. Formaldeyde is emitted by old buildings especially when humidity and temperatures are high.

### 3.4 Respiratory system

Together with air composition it is worth adding the respiratory exchange ratio since 11 m3 are required every 24 hours. (Kirk Smith, 2011)
The Respiratory exchange ratio is:
R= Rate of $CO_2$ Produced / Rate of $O_2$ Consumed = $CO_2/O_2$.
As standard, $CO_2$ is produced at rate of 200 mil / minute while $O_2$ is consumed at 250 mil per minute. Hence, the respiratory exchange ratio is 200/250 = 0.80
Since respiratory exchange ratio changes under certain conditions, air pollution interacts with an individual's vulnerability affecting individual health in different ways.
When air is polluted, the respiratory exchange ratio is higher, and impact of the pollutants on the human body is more severe.

### 3.5 Dynamic nature of air and secondary pollutants

The state of the air is highly dynamic since substances react and interact with other substances due to the function of heat as a catalyst, forming what is called Secondary Pollutants, more harmful to human health and nature. Some trace gases are defined as long-lived or inert gases because they do not react readily in the air, like carbon dioxide, nitrous oxide or nitrogen. Other trace gases have a variable status because they react so quickly and are referred to as short-lived gases (Sulphur dioxide $SO_2$, ammonia $NH_3$, ozone $O_3$). They are toxic to human health and vegetation, move slowly and can be detected in industrialized areas. Trace gases are transformed by the sun's energy into new chemical compounds. Nitrogen dioxide $NO_2$, for example, produced by industrial plants or combustion processes, when exposed to sunlight, is split into nitric oxide and atomic oxygen.

### 3.6 Further chemical reactions

The chemical process continues with other reactions (John Seinfel, 2005). Atomic oxygen, reacts with molecular oxygen ($O_2$) forming ozone ($O_3$), a powerful oxidant, one of the most important pollutants in industrialized areas. Europe, US, China, India, Japan due to vehicles and industrial plant emissions ozone precursor gases, suffer from ozone impact on health and nature. Sulphur, emitted as sulphur dioxide, is another example. Once in the air it is transformed into particles of sulphate which reacts with ammonia becoming ammonium sulphate which interact with nitric acid producing ammonium nitrate a very volatile and toxic particulate leading to enhanced nitrous oxide emissions a threat for the human genetic structure.

### 3.7 Particulate Matter (s)

Many of the pollutants emitted by human activity are gases and once in the atmosphere they interact with other gases and are transformed into particles. This phenomenon is defined by chemists "aerosols" (not really as the sea spray we enjoy during windy day at beach), and particles are called Particulate Matter. Particulates can be solid or liquid and, depending on their chemical composition, they become droplets in the moist air, returning to solid particles as the air dries. Looking at the statistics, areas with high rate of Aerosols are associated with high human mortality.

Science has proven the health effects of particulate matter and ozone, another pollutant associated with high mortality rate. Sulphur is emitted as Sulphur dioxide SO2 and Nitrogen as Nitrogen dioxide NO2. These gases interact with other gases as previously said, becoming other toxic gases. SO2, for instance, becomes Ammonium sulphate when ammonia NH3 is in the air, which is created through the interaction between Nitrogen and hydrogen atoms.(D. Fowler, 2013). Combustion in general and car exhaust fumes change the form of many substances releasing a variety of other air pollutants which have short and long-term effects on human health. Some of them cause more serious illness like benzene which damages cells' genetic structure causing cancer.
To sum up, the air composition is continuously changing, pollutants persist for years and migrate around the troposphere exposing different populations, in different countries at different times.

4. Indoor air pollutants

According to research (D.Brooks, 1992), the exposure of pollutants is five times higher indoors than outdoors. Therefore air contaminants in buildings cause serious effects on human health. Although outside pollutants enter in buildings, health and safety managers must also face almost 1000 indoor air contaminants which are intensified by doses, concentration rates, humidity, temperature and lighting. Indoors air pollutants are classified in the following groups: asbestos, radon, biological contaminants, second hand smoke, formaldehyde, lead, sick building syndrome, organic chemical, stove and heaters.
Asbestos is a mineral fiber used in building construction materials, found in older plants, insulation materials, textured paints and other floor tiles. Asbestos exposure causes lung cancer and mesothelioma a rare form of cancer and debilitation of respiratory system. Radon is a radioactive gas produced when uranium breaks down. This process occurs in every building since uranium is a component of the buildings foundations.

The exposure to radon (breathing) affects lungs health leading to lung cancer. Biological contaminants refer to building dust, bacteria and pollen. These contaminants trigger allergic reactions, rhinitis and asthma. Second hand smoking depends on the interaction between the burning end of cigarettes and air compounds. It includes more than 4000 compounds which are strong irritants, some of them are known to cause cancer. Formaldehyde is a chemical used to manufacture building materials and industrial products. In combination with other chemicals it is used in numerous manufactured products, such as in the textile industry or chemical industries. Formaldehyde causes watery eyes, nausea and breathing difficulties. Lead is found in the air, drinking water, water pipes, food, deteriorating paint and again dust. Lead affects all body organs causing convulsion, coma and death. Lower levels of it affect the brain, blood cells, kidneys and the nervous system. Sick building syndrome refers to the deterioration of building and includes air pollution sources and poor maintenance. Office furnishings, paints, adhesives, copy machines, printers, also contribute to indoor air pollution. Symptoms include eyes irritation, as well as nose and throat, skin dryness, headaches and nausea. Sick Building Syndrome influences also the organisational climate and human relations. Organic chemicals refer to paint, varnishes and wax, solvents. They are very toxic and affect eyes and respiratory system, headaches, visual disorders, memory impairment and other chronic illnesses causing cancer. Stove and heaters are additional sources of pollutants due to the combustion process. Kerosene and gas space heaters release carbon monoxide, nitrogen dioxide and particulate matter affecting workers' health through direct and indirect indoor air pollution.

## 5. Health effects of air pollution

### 5.1 Scientific evidence

Evidence connecting human health to air pollution comes from toxicology and epidemiology and occupational epidemiology. The above-mentioned effects of pollutants on human health are just a few examples. Occupational epidemiology offers an exhaustive list of relationships between air pollution and workers' health. A common health effect reported by WHO occurs in the respiratory system. WHO has identified a broad range of adverse respiratory diseases associated with air pollution ranging from death to reduced quality of life, including some irreversible changes in the physiological functions (D.B. Peden, 2005; H. Gong, 2004).

New epidemiological studies show that exposure to air pollutants during pregnancy are linked to intrauterine growth restriction and pre-term delivery (M Maisonet, 2004). Sub-clinical effects, such as temporary deficits in lung function or pulmonary inflammation occur in most of those exposed while mortality occurs in a few. The total impact of air pollution is likely to exceed that contributed by less frequent but severe outcomes. Premature mortality is the tip of the iceberg, representing a small fraction of all effects associated with air pollution (WHO, 2005).

### 5.2 Short and long term effects

Relationships between pollutants and workers' health should be understood correctly, so as to identify both acute and chronic effects of air pollution. Studies, both in Europe and The United States, suggest that the exposure-response relationship between particulate pollution and mortality is essential linear (increasing exposures=increasing effects frequency). The effects of pollutants occur even at very low levels, explaining why a large proportion of the population is affected by air pollution.

Besides the high frequency of less severe effects, it is important to consider the chronic effects brought about by less severe effects later in life (C.A. Pope, 2000). The combination between the proportion of population affected and the severity of health effects, shows that after premature mortality we can rank hospital admissions, emergency visits, restricted activity or reduced performance, medication use, physiological changes in pulmonary or cardiovascular functions, impaired pulmonary function, sub-clinical effects.

## 5.3 The influence of susceptibility

The broad array of health effects is explained by differential susceptibilities to pollutants, depending on both host (age, health status, diet, genetics) and environmental factors (housing, workplace and neighbourhood conditions). As previously stated, a key determinant of susceptibility is the socioeconomic status. A growing body of occupational epidemiology suggests that economically disadvantaged population groups may experience a disproportionately higher health burden caused by air pollution (M. O'Neill, 2000). The understanding of the biological mechanism through which air pollution exerts its effects has evolved quite rapidly over the last decade. Evidence suggests that the PM effect manifests itself through several interrelated pathways involving oxidative stress and inflammation.

Inhalation of PM triggers inflammation in the smaller airways, leading to an exacerbation of asthma and chronic bronchitis, airway obstruction and decreased breathing. PM also interfere with the clearance and inactivation of bacteria in lung tissue, epithelial permeability and macrophage function acting as an immunosuppressor by undermining normal pulmonary antimicrobial defence mechanism (J.T. Zelikoff, 2003). The cardiovascular system is also affected by inflammatory response which induces transient hypercoagulability, progression of atheroscleroris and increased vulnerability to plaque rupture. Evidence has been accumulated on cardiac control, since air pollution leads to changes in heart rate variability and arrhythmia in susceptible individuals. (H.C. Routledge,2003; T. Suwa, 2002; A. Peters, 1999; A. Seaton, 2002).

## 5.4 Risk assessment

Risk assessment and relations between air pollution and air effects are provided by WHO for Particulate matter, Ozone, Nitrogen dioxide, Sulphur dioxide (WHO, 2005). Health effects of air pollution are classified according to short-term exposure (Daily mortality, Respiratory and cardiovascular hospital admissions, primary care visits or medication, days of restricted activity, work absenteeism, physiological changes) and long-term exposure (Mortality, chronic respiratory disease, lung cancer, chronic cardiovascular disease, Intrauterine growth restriction). Notwithstanding the extensive application of risk assessment in epidemiological studies, the investigation on the impact of air pollutants on workers' health, beyond current scientific modus operandi has yet to be implemented.

## 6. Air pollutants as Mutagens

### 6.1 Mutagenicity

Atmospheric emissions spread over long distances, permeate into the water, soil and living organisms. Most air pollution is gasses while particulate matter are the second pollutant group forming a mixture of organic and inorganic substances. Human breath is exposed to both air pollutants and secondary pollutants which cause a mutagenic effect. If the quantity of daily breath (11 m3 of air every 24 hours) is exposed to polluted air, the probability of disease occurs.

Epigenetic science has proved that air pollution effects include changes in the human genetic structure (DNA). Since DNA is formed by a nitrogen basis, each pollutant reacting with this chemical composition of DNA leads to a genetic change and related diseases such as cancers and leukaemia.
The harmfulness of particulates to DNA depends on the particulate diameter. Air containing particles smaller than 2.5 micrometer (-10 meter) is the most harmful pollutant to human and animals since it penetrates the respiratory tract settling on the surface of alveoli and therefore processes within the blood system. The complexity of pollutant composition and reaction once emitted impede the epidemiological observation on air mutagenicity.

### 6.2 Chemical compound and consequences

A huge number of compounds representing different chemical classes can be found in polluted air and those compounds form complex mixtures of unknown biological consequences (K. Piekarska, 2009). Studies show that the nitro-amino-oxy PHA derivatives are classified as "mutagens". Considering that mentioned compounds have a synergistic effect, their isolation and the identification or their "reaction" is vital for human health. Mutagens are physical or chemical agents which change the genetic structure (DNA) leading to cell mutation and subsequent death. As mutations cause cancer, mutagens are therefore likely to be carcinogens. It is worth noting that not all mutations are caused by mutagens. Occupational epidemiology shows how different mutagens act on the DNA differently. Powerful mutagens result in chromosomal instability or modify the DNA sequence. In particular, changes in nucleic acid sequences by mutations include substitution of nucleotide base-pairs and insertions and deletions of one or more nucleotides in DNA sequence. Images of DNA changes by mutagens generated by tobacco smoke (benzo(a)pyrene), are quite impressive.

Many metals, such as arsenic, cadmium, chromium, nickel and their compounds may be mutagenic but they are also associated with the production of other chemical reactions leading to
death.
The Latin meaning of mutagen is origin of change. Hippocrates, Paracelsus, John Hill, Percivall, Pott, Herman Muller, Charlotte Auerbach among others provided evidence on different mutagens and their serious effect on health. The industrial revolution, being the origin of the change of western society brought mutagens up to the current economy based on continuous accumulation and growth (J. Evans, Modeling of Air Pollution Impact, Harvard University Press, 1996). The watershed of development is entrenched in the will and capacity to prevent mutagens by taking the sustainability as the imperative to be followed by economic and social actors.

## 7. Understanding Air Pollution Prevention

### 7.1 The general framework

Literature on Prevention (US EPA, 2003) includes three areas following the cycle of pollutants: sources, transportation and receptors. At source, emission ratios and type of pollutants are studied within other physics variables such as height, temperature, pressure and the speed of exit. The transportation issue includes wind speed, moisture, temperature, physical transportation and chemical reaction, the atmospheric chemistry and physics. The meteorology variables such as rain, dry dispersion, influence the pollution dynamic but are not part of a prevention programme. Receptors, in their turn, include sea, earth, humans, animals, monuments, buildings and the atmosphere itself. While air pollution prevention cannot be applied in the Transportation phase, Prevention at source and at receptors is feasible. Needless to say Prevention at Receptors is seen as the last resort, achieved by Air quality standards, Air Quality Goal and Guidelines. Since Air Quality Standards are country specific and depending on policy makers sustainability culture, air prevention at source is the preferable solution. The prevention policy is based on knowledge of pollutants and the emission context. For instance, PM sources are identified in Construction sector, Agriculture, Waste and Cigarette smoke, CO sources are caused by incomplete combustion in the energy, transportation and Industry sectors, SO2 sources are identified in burning coal and oil from Industry, transportation and energy sectors, NO2 sources from industrial processes, car exhausts, VOC sources from industrial processes, waste and transportation, lead sources, again from industrial processes and transportation. As far as secondary pollutants are concerned, SO2 Sulphur dioxide becomes the source of H2SO4, NO Nitrogen Oxides are the source of Nitrogen dioxide NO2 and HNO3 Nitric acid, whereas NO and VOC Volatile Organic Compound (paints and lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, office equipment such as copiers and printers, correction fluids and carbonless copy paper, graphics and craft materials including glues and adhesives, permanent markers, and photographic solutions) form Ozone O3.

## 7.2 Aims of Air pollution Prevention

The aims of air pollution prevention are to reduce the quantity and the hazardous character of pollutants. (OECD, 2000). Related activities are applicable on a life-cycle basis and articulated into three types: strict avoidance, reduction at source, product re-use. Subsequent processes, such as Recycling, Incineration, Land-filling belong to Waste Disposal. According to the OECD definition, Strict avoidance involves the “complete” prevention of waste generation by virtual elimination of hazardous substances or by reducing material or energy intensity in production, consumption and distribution. As far as reduction is concerned, reduction at source involves minimising use of toxic or harmful substances and minimising material or energy consumption. Product re-use involves the multiple use of a product in its original form, for its original or alternative purpose with or without reconditioning. As a result, air pollution prevention occurs before pollutants are emitted or products are identified as waste. It is worth noting the difference between air pollution prevention addressed to relative reductions pollutants and other activities and programmes focused on absolute pollutants reduction.

## 7.3 The combination of prevention and recycling

While air pollution prevention will never make recycling obsolete, the application of both prevention and recycling will have a greater influence on overall waste prevention than the individual application of one or the other. (see OECD Manual, Strategic waste prevention, 2000). In fact, high rates of prevention result in fewer materials being recycled. In its turn, recycling appears as the only solution in the case of toxic and dangerous substances. Since recycling and prevention are to be substituted, the increase of recycling waste acts as a disincentive to waste prevention. Depending on circumstances, specific characteristics of industries, products or materials lead to the decision to recycle rather than treat as a prevention issue. The recycling industry could be negatively influenced by prevention programmes. Therefore, the choice between recycling and prevention should be taken after a thorough evaluation on multiple factors including both technical and social.

The most important difference between strategic waste prevention and recycling is the ultimate focus. Strategic waste prevention, addressed to materials, contributes to a cleaner air encouraging Eco-efficiency policy, Industrial ecology, Integrated pollution prevention and control, extended producer responsibility and integrated product policy. Strategic waste prevention is closer to the green economy and its rational is often drawn by the specification of what, how, when and who complemented by two other prevention concepts like why and where to finalise prevention policy. Waste prevention is (in its most basic sense) an old behaviour pattern. The use of material in a frugal manner concerns any survival goal. Repairing a damaged item rather than buying a new one, saving used materials for re-use, producing objects and tools that maximize efficient use of raw materials are part of a society based on the principles of green economics. Pressure to grow and to accumulate is in contrast with the waste prevention habit impeding the practice of producing the same product with far fewer materials. Consuming less, excluding toxic materials are not commonplace in the liberalistic economy and in people's minds convinced by a bombardment of marketing. Waste production, due to materials, complements waste emissions leading to a huge toxic waste and related health impact. This is why prevention programmes based on relative reductions in waste generation (per unit output) are not enough. Absolute waste reduction should be broadened, overcoming barriers associated with inadequate information, lack of system analysis and lack of environmental sensitivity.

## 8. European policy on prevention

Since the EU Council Directive 78/176 on waste, a number of substantial changes have been made in European legislation concerning air pollution prevention. Several sectoral directives lay down specific minimum requirements including emission limit values for certain industrial activities such as large combustion plants, waste incineration, activities using organic solvents. The Directive on Industrial Emission (IED) 2010/75/EU replaces the IPPC Directive (Integrated Pollution Prevention and Control, 2008/1/EC) and summaries the European Union's work on Prevention strategy. The European Strategy on Air Pollution was published in 2005 through the Communication 2005/446. Following the Communication on the Clean Air for Europe (CAFÉ) the Strategy includes the assessment of health impact of pollution. Ground level ozone and particulate matter are considered pollutants of the most concern, leading to premature mortality. Ozone is not emitted directly but formed through the reaction of volatile organic compounds and Nitrogen oxides in the presence of sunlight. Particulate matter, in its turn is emitted directly (primary particles) but it is also formed in the atmosphere as secondary particles from gases such as sulphur dioxide, Nitrogen oxides and Ammonia.

In 2013 a loss in statistical life expectancy of over 8 months due to 2,5 PM in air was reported. This is equivalent to 3.6 million life years lost annually and 340.000 premature deaths. In monetary terms, the damage to human health is estimated at between 190bn euro and 610bn euro per annum. The latest science also shows that some environmental impacts of air pollution, such as acidification and eutrophication are more serious than expected. The EU Strategy points out that in view of these costs taking further action is not an option. As a result, the Strategy had the objective to achieve levels of air quality that do not give rise to significant negative impact on and risk to human health and the environment, through two means: simplification of air quality legislation and control measures. The Directive on industrial emission 2010/75/EU can be considered a first result towards air quality prevention and related abatement of SO2, NOx, VOCs, NH3 emission levels.

The IED Directive (84 articles and X annexes) covers definitions, general principles and prevention obligations, best available technologies, emission limit values, installations requirements, environmental inspections, controls of emissions and monitoring and special provisions for installations and activities using organic

solvents. Technical issues are presented in Annexes. The European Pollutant Release and Transfer Register is the new Europe-wide register providing data reported annually by some 28.000 industrial facilities covering 65 economic activities. This register is a remarkable instrument for prevention since it contributes to transparency and public participation in environmental decision-making.
The decision to designate 2013 as the Year of Air reflects the concern about the impact of pollutants on human health. The European Environment Agency plays an important role in prevention policy. Air Quality in Europe Reports provide data on sources and effects of Particulate Matter, Ozone, Nitrogen Dioxide, Sulphur Dioxide, carbon Monoxide, heavy Metals and Benzene.

## 9. Strategic air pollution prevention

### 9.1 Green technologies

Air pollution Prevention or its abatement is expensive and it is perceived as a part of business costs and an inevitable cost of growth which can be passed on to consumer price. Costs of compliance with all environmental regulations go beyond the capital investment of control equipment and include engineering costs, tender and bidding costs, operational costs, costs for training dedicated staff, costs associated to monitoring and statistics and laboratory costs. Due to the aforementioned costs, investment in green technologies as a way to prevent air pollution in same circumstances is not feasible. The green technology is a technology which achieves a cleaner less polluting production. A usual case, often mentioned, refers to the conversion of a coal-fired electricity plant to a natural gas technology which cut unburned hydrocarbons (UHC), lowered carbon dioxide ($CO2$), mercury, PM, $NO2$, and sulphur dioxides. In addition, gas fired plants are cheaper to build. Another example is the case of US Air Force which decided in 2003 to destroy material rather than incinerate it. Disintegrators provide an alternative to incineration. In this case, the reengineering of destruction processes costs less than incineration costs.

### 9.2 Prevention programmes

Pollution Prevention programmes applied to enterprises (called P2) are demanding and not always practical. (N. P.Cheremisnoff, 2001).
Needs analysis is the initial phase aimed at gathering information for a baseline description of operations and their pollution impact. Environmental performance and financial performance are taken into account. In plant assessment the next phase is followed by the third and conclusive phase devoted to corrective action formulation. Monitoring of gaseous emissions is not always detectable and measurable and thus it is an indirect estimation. Several relationships are measured such those between odours and unit operations, vapours and employee irritations, gaseous emissions and respiratory problems among workers and so on. In essence, the environmental impact and human health are considered in a whole assessment document containing recommendations on production process changes, equipment to be changed, changes

in process control, use of dispersion in place of solvents, the revision of raw materials flows, raw material substitution, process substitution with cleaner technology. Economic evaluation, which is of considerable importance for the company, accompanies the final assessment together with the full cost accounting.

## 9.3 The choice of Air Pollution Prevention

The 1990 US Clean Air and Pollution Prevention Act shifted the control and measurement strategy to the Pollution Prevention Strategy emphasising the reduction or elimination of waste production “before” it is emitted into the environment (L. Theodore, 1992, T.E. Higgins, 1995). At industrial, commercial or household sites, Pollution Prevention requires the substitution of a process that is less hazardous to human health and the environment. Pollution Prevention also foresees innovative solutions to the process, equipment or plant operating practices towards the elimination or reduction air pollution. More efficient maintenance procedures or conservation of energy at the source methods are also part of the P2. Effective air pollution prevention steps include the source reduction, recycling, waste treatment and disposal, as a last resort. Regarding Source reduction, material substitution and source control are the most useful methods applied. The former occurs when a fuel source or raw material is replaced by a less toxic component which is equally suitable for manufacturing, as in the case of the replacement of chlorofluorocarbons with hydro chlorofluorocarbons. A typical example of material substitution refers to coal and other ores before subjecting them to the manufacturing process. Source control involves changes in the equipment and operational settings of a plant or segregating toxic chemicals from one another to reduce the number of dangerous events to public health.

When other at source reduction techniques are not possible Recycling appears to be the option. In this case a waste product is used as a fuel resource to power a manufacturing process. Since waste exchange between industries is based on economic convenience, when this is not the case recycling is not pursued. Recycling also involves the chain between factory and consumer. In this case, the financial variable is added by the ecological spirit of the consumer, which is culture-based. When a chemical composition or hazardous material cannot be reduced, substituted or recycled, its treatment is the last resort and includes incineration, chemical alteration or physical treatment.

Treatment refers to pollutants that cannot be reduced or recycled or transformed into less toxic chemical components and includes incineration - either biological, physical or chemical. The aim of incineration is to reduce the amount of toxicity of a pollutant. When treatment is not feasible, the last resort is disposal the least attractive option. Disposal is carried out through land farming, deep well injection, land filling and ocean dumping. Regrettably, these systems produce pollutants and are not the right response.

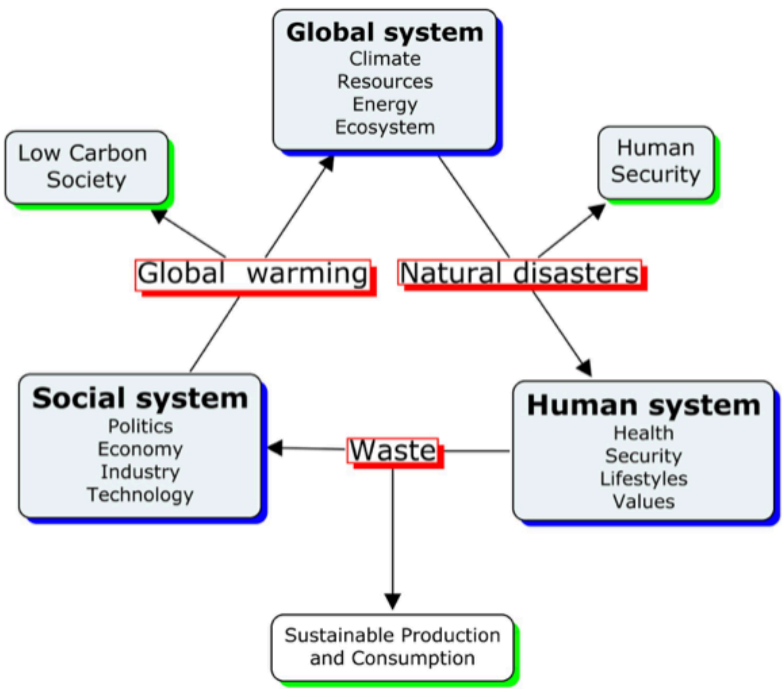
## 10. Role of education towards sustainable mindset

### 10.1 Cooperation among science, industry and educational institutions.

Emissions from Industry, public and private buildings, transportation and other combustion-based human activities are threatening not only climate patterns or the environmental balance but they also impact on human health leading to diseases and premature death. Reducing and Preventing air pollution are two different strategies of two opposing ways to address development and growth. In this effort, close to the development approach and far from business as usual cynicism, cooperation among researchers, industry, general public and educational institutions is the imperative. Foundations for a sustainable society depend on the preventive principle. Since the preventive paradigm must be learnt, strategic education should be organised so that this goal can be achieved as soon as possible.

### 10.2 Sustainability science

Rather than emphasize a sustainability concept based on the World Commission on Environment and Development, (satisfy current needs without compromising the ability of future generations to meet their own needs) sustainability science as a discipline that unifies global, social and human systems, should be strengthened (H. Komiyama, 2011). The “global system” includes the geosphere, atmosphere, hydrosphere and biosphere. The Earth provides natural resources, energy and a supportive system. The “social system” comprises the economic, political, industrial and the societal base for a fulfilling human existence. In this realm, for instance, the declining birth rate is interpreted as the unsustainability of the family. In its turn, the “human system” is connected to the social system and affects directly the health and survival of human beings.



Poverty, hunger, disease, lack of housing and exclusion, religious tensions or wars are part of the human system. Relationships between the above-mentioned domains define problems humanity must face. The interaction between the social system and global system leads to global warming whereas the links between the social system and human system causes mass production and therefore waste. The links between human system and global system leads to poverty, hunger and diseases. As a result, a low carbon society is the response to global warming, sustainable production and consumption the response to waste and the human security the answer to poverty and hunger.

Sustainability science refers to the comprehensive and holistic view underlined by the aforementioned interactions. It would be beneficial to shift the focus from the definition outlined in the Brundtland Report towards a more useful framework drafted by sustainability science.
Two obstacles impede progress towards sustainability science:
the complexity of the problems;
the specialisation of science that seeks to address the problems.
Multiple factors behind the sustainability crisis are not faced by an overarching strategy. Rather, the compartmentalization of disciplines means that the analysis takes a highly restricted perspective. The period of explosive expansion started in the 1950s and not arrested by the economic crisis of 2008-2013 coincides with the severe period of air pollution. What is worse is the "mobility" of pollution generated in one part of the world but impacting on humans' health in entirely different areas. In addition, the attempt to provide uniform solutions to different, even if global concerns, is another part of the problem. Yet, dialogue and consensus, crucial factors towards sustainability science, are not so widespread among experts and academics, therefore aggravating the identification of innovative and trans-disciplinary solutions.

## 10.3 The need for a comprehensive view

Segmentation and specialisation of knowledge is due to the massive flood of information from libraries and on line source. For example, over 3000 articles were published in 2010 alone (Y. Kajikawa, 2010) on sustainability and this number is growing exponentially. Needless to say Knowledge advances society and prosperity, but the problem lies in the lack of a comprehensive view. Scientists are trained to produce specialized bricks of knowledge without looking at the whole building. Regarding sustainability, there is a general agreement about its meaning as the ability to sustain a certain state or level. However, when the World Commission on Environment and Development relates sustainability to development as "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987)" some doubts are raised by green economists. The current generation concept, in fact, is not a "neutral" concept but entails differences among current population cohorts and their needs. Who decides what needs should be met, those of industrialized countries or those of others? The second difference regards the nature of needs, often assimilated to physical goods measured with money rather than other kinds of goods, such as health, education or spiritual needs. It is difficult to accept that 1,3 billion people who live on 2 dollars a day could think about future generation needs and can afford the cost of the polluter-pay principle. Yet, the treatment of future generations seems difficult as they cannot express their needs and wishes nor enter negotiations. Furthermore, ethical issues are involved when the efficiency principle is considered. Since pollution is part of human activity and could not be eliminated (Laws of thermodynamics) and pollution is often a by-product of beneficial processes (health care), setting pollution targets requires the evaluation of cost and benefits in monetary terms. This might be judged unethical. As a result, an economically efficient pollution target may not be socially optimal (P. Singh, 2007).

## 10.4 Trans-disciplinary

The UN University analysed the academic landscape of sustainability through a citation network analysis of 29.391 papers including the concepts as sustainability. Regrettably, results showing 15 main domains (Agricolture, Forestry,Business, Soil, Energy, Water, Wildlife, Health, etc) do not include Air. This is an example that data and information are not enough. Knowledge is identified through modelling and modelling is a process that replaces the part of reality with an abstract representation of the world that has a similar but simpler structure (Y. Kajikawa, 2011). This is why researchers are building a common modelling framework for sustainability science. Forecasting science is another example in that it includes Goal-settings, indicators design and measurement, casual chain analysis, problem-solution framework. Since forecasting is not based on data, backcasting is needed to use available data, but backcasting has no change options. In conclusion, sustainability science needs both backcasting and forecasting, overcoming the separation of disciplines toward a multidisciplinary and trans-disciplinary approach. This effort combines engineering and psychology, economics and governance, in short science and humanities.

## Conclusion: a collective action towards prevention

Concomitant to the comprehensive perspective goes the need for effectiveness of action. It is said that knowledge without action cannot change a situation and action without knowledge leads to uncertain results (G.D. Brewer, 2007). Action-knowledge is a key relationship in the design of collective action indispensable to transform current society into a sustainable community. The collective action points out that a single action has a limited impact on sustainability. Without an orchestration towards sustainability, all activities by numerous actors have a marginal effect. This collective action should be built through a first stage of decomposition and analysis of unit action, followed by a second stage relating to the integration of multiple actions into a new and innovative action which will be the collective action after the promotion and agreement of common goals. Collective action needs transparent flows of information between actors and requires a network of networks so that knowledge promotion, mutual learning, trust and strong social capital are achieved. By strengthening a network of networks, knowledge is shared, leaning processes become mutual, skills and resources are used in a complementary way, innovation is breathed collectively. These relational activities have the capacity to overcome the tendency to apply a single solution, even if it were powerful, to many problems, allowing plausible solutions to meet temporal and spatial factors. To this end, a partnership-building approach is needed to involve stakeholders, organise responsibilities, reach credible commitment and legitimacy of the collective action. In short, everyone should in the words of Wangari Maathai be a hummingbird and do the best they can.

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