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foR Assessment
of Integrated Strategies
At regional and Local scales

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Summary

This document results of the analysis of the collected activities of the database on Air Quality plan compared to the state-of-the-art on health impact assessment methodologies. It shows the various options taken by investigators designing Air Quality action plans when they envisage to use health impact to further support decisions. Questions and comments are collected to define research priorities for the integration of HIA in an Integrated Assessment Modelling framework (IAM).

Version History

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Summary of Changes

Version	Section(s)	Synopsis of Change
0.1	All	Framework of the document
0.2	All	Review of the first version and change of structure after TM
0.3	All	Integration of comments on the new structure of the document and comments from stakeholders

Contents

1 Introduction

The World Health Organisation (WHO) has been promoting the use of a Health Impact Assessment (HIA) for over 20 years as a method for linking health with economic and institutional framework strategies towards sustainable development (Winkler et al., 2013). "HIA is a mean of assessing the health impacts of policies, plans and projects using quantitative, qualitative and participatory techniques" (http://www.who.int/hia/en/). Another essential feature of HIA is stakeholder participation, involving people affected, to be affected or who have an interest in a decision (Kemm & Parry 2004). The WHO European centre for Healthy Policy (1999) defined HIA as "*a combination of procedures, methods and tools by which a policy, programme or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population*" (Wismar 2007).

Integrated environmental health impact assessment (IEHIA) is defined as an assessment of health outcomes due to environmental exposure and to policies and other interventions that may affect the environment in general, in order to take into account complexity, inter-linkage and real uncertainties. It aims to bring together existing methods within a more coherent system, and to extend these methods in order to provide a more comprehensive methodology for assessing complex, systemic risks and policies (Briggs 2008). An overview is given in Figure 1.

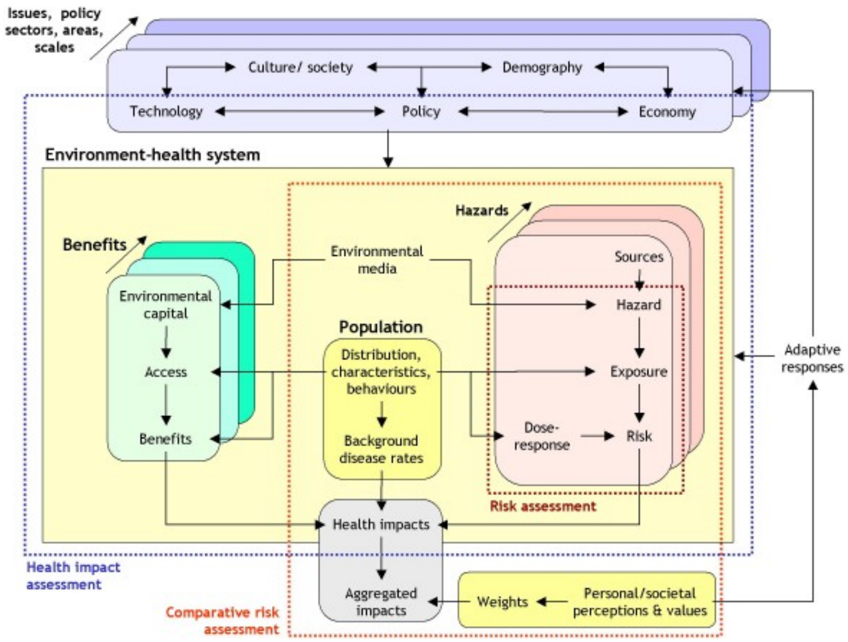

Figure 1. Overview of integrated assessment. Figure from Briggs, 2008. The Health Impact Assessment (HIA) is part of the integrated assessment.

2 State-of-the-art of HIA methodologies

HIA addresses different methodological issues, which must be clarified for proper interpretation of results by policymakers (Medina et al., 2013). Different methodologies exist for making a HIA. The aims and objectives of the assessment, data availability, resources, and time-frames have an influence for the HIA methodologies used in particular assessment. As different methodologies and approaches exist, state-of-the-art is defined by providing an overview of the most common methodologies, including (dis)advantages. In a final chapter recommendations for performing HIAs will be given. By clarifying the methodology to policymakers, they will be able to make a more balanced or scientifically weighted decision for the different policy options or scenarios. HIA is usually performed in a relative way by which different options, interventions can be weighted. Scenarios and interventions are part of the assessed alternatives chosen by policy-makers.

2.1 Approaches

The actual health impact is calculated compared to a reference scenario. A reference scenario can be e.g. zero pollution, decrease in pollution *etc*. The actual disease burden can then be compared to the reference scenario. Environmental and policy considerations that influence population health need to be integrated into the scenarios which will lead to health-related decisions taken. Different approaches exist for making a comparision to the actual situation.

In terms of choices for selecting the approach to be compared to the actual situation, we have to distinguish between **predictive**, **retrospective** or **counterfactual approaches**.

A predictive approach assesses "*what will be the health of the population in a given future time framework if we decrease pollutant levels*". The predictive approach aims to assess the future health impact of a given policy but requires making assumptions about the future trends in population and health events; about the time required to achieve the decrease of pollutant levels; and about the lag between the decrease in pollutant levels and the occurrence of health benefits. The alternative scenarios describe the world as it might look in the future if certain changes are allowed to happen (e.g. new policy developments, technologies or environmental changes). The reference scenario describes the current situation, but (more strictly) should project this into the future – i.e. a 'business-as-usual' scenario or as the result of a given emission-control scenario (IEHIAS website). Several projects are based on a predictive approach, such as the Clean Air for Europe (café) cost-benefit analysis and the Committee on the Medical Effects of Air Pollutants (COMEAP) assessment on the mortality effects of long-term exposure to particulate air pollution in the United Kingdom (COMEAP 2010).

Advanced tools are required by this approach, for example, Fattore et al. (2011) used the air quality health impact assessment software AirQ 2.2 by WHO to assess the human health effect of PM2.5. The result of their study shows that short-term exposure to PM2.5 was the most significant health impact on 24 000 inhabitants from 2 cities (Fattore et al, 2011). This approach provides quantitative data on the impact of diverse pollutants (in this study, PM, O_3, NO_2) on health status in terms of attributable proportion of the health outcome, annual number of excess cases of mortality for all causes and cardiovascular and respiratory diseases. Long-term effects were estimated for PM2.5 as years of life lost. Another way to estimate air quality impact under scenarios is by the IOMLIFET tool, developed by the Institute of Occupational Health (Miller, 2006).

The retrospective approach could equally be described as an evaluation of public policy on health outcomes and to confirm or to discard hypotheses (Dugandzic, 2006). It assesses the outcomes in comparison to an earlier state. The feature that distinguishes a prospective from a retrospective cohort is whether the outcome of interest has occurred at the time of the investigator initiates the study. A prospective cohort study is one in which a group of people is followed over time to see if they acquire a disease/outcome. A retrospective study is one in which the disease status of a cohort of people is known. (Epidemiology in Medicine, Hennekens and Buring, 1987). Currently, Brook et al (to be published), choose a retrospective cohort to assess knowledge and provide information to inform policies on Air Quality Management to finally understand the health effect of Air Pollution in Canada (Brook HEI workshop, Brussels January 2013).

The counterfactual approach comes close to the predictive approach. It assesses the difference in health outcomes between what is currently observed and what could have been observed if air-pollutant concentrations had been lower (opposite to current facts) and the benefits for health had been achieved for the actual population. This approach gives an idea of the current burden of air pollution on health, with the assumption that policies targeting reductions in pollutant levels could lead to a reduction in the assessed health burden, all the other parameters being equal to the reference situation. In accordance with the considered pollutant, the impact is generally evaluated under several counterfactual scenarios of air pollution reduction based on WHO guidelines and other national or international Ambient Air Quality Standards (EU AQS, US NAAQS, etc.). The approach builds on the epidemiological concept of an attributable fraction defined at the population level as the proportion of disease cases that can be attributed to a given exposure level.

This approach has been used by the Apheis project (Medina et al., 2005; 2009), in the Aphekom project (Pascal et al., 2013), in the second part of the COMEAP report (COMEAP, 2010) and also in the WHO Global Burden of Disease project (Cohen et al., 2005). Similarly, Jahn Heiko et al., (2011) used this approach where in order to estimate the potential changes in mortality for each air pollution reduction scenario, they use current air quality standards and guidelines (PM10: Chinese NAAQS and WHO AQG and PM2.5: EU AQS and WHO AQG and by increasing per 1 µg/m³ to determine the relative risk for both PM10 and PM2.5). Counterfactual approach is also used to evaluate the impact in terms of numbers of attributable deaths associated to air pollution based similarly on WHO AQG and EU AQG (Baccini et al., 2011).

These last authors present results of a health impact assessment of short-term effects of particulate matter ≤10 µm in diameter in Italy (2003-2006). The impact was evaluated in terms of numbers of attributable deaths under several counterfactual scenarios of air pollution reduction based on WHO AQG and EU limits. They applied two different methods for calculation of attributable deaths. The opportunity to use one approach or the other depends on the chosen counterfactual scenario, while using macro modelling is the simplest way to quantify the impact under counterfactual scenarios defined in terms of yearly average, the micro approach also allows evaluation of the impact under counterfactual scenarios defined in terms of daily concentration. The health impact assessment was conducted by specifying different reduction scenarios (Baccini et al., 2011). As regards in daily exposure, during the workshop HEI in Brussels, Flemming R Cassee suggests that immediately and in subsequent days, repeated (multiple days) exposures to PM may result in larger health effects than the effects of single days (Flemming R Cassee_RIVM, HEI Brussels January 2013).

The scenarios used in any of the above approaches are based on the policy to be assessed. They can vary from no intervention, also know as business as usual (BAU), to a measured intervention such as ½ the emissions or ½ the exposure of a specific pollutants, or lead to reference values for that specific pollutant. The Apheis (Medina et al., 2005; 2009) and

APHEKOM projects (Pascal et al., 2013) have used WHO guideline values for the HIA and made later its translation into the changes in life expectancy of a population or monetarisation of the health (Chanel et al., – APHEKOM, to be published).

2.2 Time series

Exposure to air pollution is associated with an increase of risks to diverse health effects, which may be translated in terms of "health indicators". When different health effects are considered, it's important to distinguish between acute effects related with short-term exposures and chronic effects resulting from long-term exposure. The impact of long-term exposure effects is often larger than those associated to short-term exposure (Beverland et al., 2012). Short-term exposure, with the capability to cause acute health effects, have traditionally attracted most concern. However, recently it has been recognised that chronic effects resulting from cumulative (including lifelong) exposures are often a more important public health problem (Briggs et al., 2009).

The impact of air pollution is usually assessed on an "annual basis", given that the adequate approach would be to assess both the total short-term effects across one year and/or the long-term effects after a lifetime. Most often the impact of air pollution on premature mortality is assessed for long-term exposure (Kunzli et al., 1999).

Time-series studies of the effects of short-term exposure on morbidity and mortality from cardiovascular or respiratory diseases continue to provide some of the most current and consistent evidence of serious adverse health effects of air pollution in Asia (HEI, 2010).

Time-series and intra-urban studies show that exposure-related factors may contribute to city-to-city differences in the reported PM2.5 concentration-response functions (e.g. cohort studies of long-term exposure to PM2.5) (US EPA, 2009).

This kind of heterogeneity is studied in APHENA project, whose purpose was to develop a common approach for the first-stage analysis of time-series data, and to conduct theoretical investigations and simulation studies to explore heterogeneity across the United States, Europe, and Canada (HEI, 2013). During this study, investigators compared two different approaches for combining information in the analysis and the participating statisticians addressed several statistical aspects of the modelling of multisite time-series data and resolved issues by theoretical development and simulation studies. This work has led to several contributions in the statistical literature and when simulation studies did not provide a clear indication of a preferable method, the APHENA investigators decided to conduct statistical analyses under all possible approaches to assess sensitivity of the results. In summary: hierarchical and meta-regression models shows that regarding the pooled estimates of pollutant effects within each region, results may differ substantially in explaining heterogeneity across regions (Klea Katsouyanni, HEI Brussels, January 2013).

Moreover, in framework of multicity time-series study, the SCALA project explored also modification across study locations. Investigators analysed the effects of PM10 and O_3 on mortality by combining information across cities to obtain summary estimates by using a meta-analysis approach. The results demonstrated that there was not substantial heterogeneity among cities in the association of PM10 with mortality (Romieu, 2012). Moreover they also showed some levels of heterogeneity for most of the causes of death in the association of O_3 and mortality.

2.3 Health-impact relationships

A distinction is made between particulate matter, ozone and NO_2.

Particulate matter is recenty the most studied air pollutant and is mainly addressed in health impact assessments.

Exposure-response functions are often derived based on epidemiological studies e.g. effect of air pollution on mortality rates. In general, epidemiological studies that have used finer spatial resolution to relate people to air pollution levels tend to report higher mortality/morbidity impacts (Tainio, 2009). Therefore a recommendation is to use in epidemiological studies, assessing the health effects of air pollution, the available most detailed exposure estimate (e.g. for pollutants with high spatial variability this can be based on personal activity-based modelling or personal dosimetry).

Pope and Dockery have emphasised the importance of **particulate matter** with aerodynamic diameter < 2.5 µm (PM2.5) from a health perspective; they indicate that this smaller fraction is of immense importance and appears to be more significant than PM10 (Pope and Dockery, 2006). Also WHO has mentioned that there is increasing evidence that the PM2.5 fraction contains the principal harmful particles (WHO, 2003). However, although fine particles are often blamed, coarse particles from e.g. tire and brake wear could be implicated in health effects as well (Riediker et al., 2008; Gasser et al., 2009).

The choice of the exposure-response functions is very influential on the outcome of the HIA process. Usually American studies (H6C: Harvard Six Cities study: Dockery et al., 1993; ACS: American Cancer Society study: Pope et al., 2002) are used to calculate the response (mortality) to particulate matter exposure in Europe. Various European longitudinal studies have recently shown results consistent with a causal link between long-term air pollution exposure and mortality in Europe as well (Filleul et al., 2005; Hoek et al., 2002; Gehring et al., 2006). The EU ESCAPE project (http://www.escapeproject.eu/structure.php, European Study of Cohorts for Air Pollution Effects), also focus on this topic and the results will be published soon. The percentage increase in total mortality estimated in the ACS for a 10 µg/m^3 increase in PM2.5 was about 6%, while in the more recent and statistical powerful studies, this percentage is between 15% and 18% (Ballester et al., 2008). Also based on USEPA expert elicitation this percentage would exceed 6% (IEc Industrial Economics Incorported, 2006). Following an at least approach (see further) an estimate of 6% can be used. However, at the 2013 HEI workshop (http://www.healtheffects.org/Workshops/Brussels2013/brussels2013-agenda.htm) on air pollution and health effects, some preliminary results of the ESCAPE study were shown and the estimate of the relative risk associated with total mortality and long-term exposure to PM2.5 in Europe was equal to 1.07 (1.02-1.13) per 5 µg/m^3 increase which is relatively larger than for the ACS study. A reason for this may be the better exposure estimate. Whereas in the ACS and H6C studies one fixed monitor for PM2.5 was used for a complete city or metropolitan area, more detailed exposure levels were obtained in the ESCAPE study.

An alternative (instead of using relative risks RR or odds ratios OR) may be the use of impact functions based on RR or OR and life table analysis. This choice is influenced by the health indicator that is going to be used. An example is given in the CAFE study. In the CAFE programme an impact function (exposure-response function), estimating years of life lost (YOLL) by chronic exposure to PM2.5 for the adult population (+30 years), was presented based on exposure-mortality relationships and inclusive life table analysis (Hurley et al., 2005). The same approach has also been tested and applied at regional scale (over Northern Italy) (Carnevale et al., 2012). In this study, considering all age categories 651 YOLL are associated per 10 μg/m^3 PM2.5 per 100,000 people considering all ages. This impact function is also supported in the NEEDS, New Energy Externalities Developments for Sustainability, project (http://www.needs-project.org/RS1b/NEEDS_Rs1b_D3.7.pdf).

For **ozone** current HIAs only takes into account effects after short-term exposure to ozone peaks (see core analysis of CAFE approach: mortality, MRAD or minor restricted activity days, hospitalisations for respiratory symptoms, use of bronchodilators, cough days, days with problems of the lower respiratory tract). More evidence is published on ozone effects after long-term exposure to ozone (e.g. for mortality see Jerrett et al., 2009). This may be taken up in future HIAs as sensitivity analysis.

HIA can be performed for **NO_2** in the understanding that impacts of other pollutants, notably PM mass, are also being quantified. Currently there is new evidence supporting HIA for NO_2 (http://www.healtheffects.org/Workshops/Brussels2013/Presentations/Krzyzanowski.pdf) Independent mortality effects of NO_2 are described in the paper of Cesaroni et al. (2013)

2.4 Threshold

Threshold is the concentration of a pollutant below which no adverse health effects are anticipated. According to WHO there is no threshold for health effects (mortality) related to exposure to PM2.5. More and more studies do find effects at the lower end of the exposure-response function (Crouse et al., 2012). Natural background concentrations for PM2.5 were estimated at 3-5μg/m^3 in the United States and Western Europe (WHO, 2005).

If a threshold value is used, this should be stated, as this can majorly influence health impact calculations. Depending on the analysis, a threshold may be used in sensitivity analysis (e.g. impact of reducing PM levels to a background concentration or a certain reachable value).

2.5 Lag time

Some chronic diseases develop slowly and the disease outbreak occurs years or decades later (lag time) than the associated exposure. Usually in HIA these lag times are not included. Different literature studies show that the inclusion of lag time only had a relatively minor effect when health effects related to PM exposure are studied (Tainio, 2009; Leksell and Rabl, 2001; Röösli et al., 2005; Hänninen et al., 2011). Relatively largest effects are found for cancers.

2.6 Pollutants, exposures & health effects

Every day, an individual is exposed to different concentrations of atmospheric pollutants as he/she moves from and to different outdoor and indoor places and those conditions affect that individual's health. Human exposure is defined as an event that occurs when a person comes in contact with a pollutant (Ott, 1982) and exposure estimates to atmospheric pollutants can be addressed to individuals (personal exposure) or large population groups (population exposure), and can be based on direct (exposure monitoring) or indirect methods (exposure modelling). Once dangerous components are identified, their health impact can be calculated to provide information on the health burden of exposure to those dangerous components and allows a decision to be taken using different scenarios.

Air quality action plans are mostly based on identified and monitored pollutants, their sources, their behaviour in the atmosphere and their effects on the environment and on human health in the context of a geographic, institutional and economic situation. The choice of the “pollutant-exposure-health effect” indicator for HIA (e.g. DALY, number of premature death, YOLL, etc.) is also defined by the scope of the intervention to be assessed.

The choice of a pollutant, a cocktail of pollutants or an indicator as proxy for an exposure situation in HIA are also restricted by the available scientific knowledge on the pollutant or cocktail of pollutants (on how to measure and what are the concentrations), on scientific knowledge on health effects and the way to measure those effects (causality) (REVIHAAP & HRAPIE, HEI 2013).

Exposure to outdoor air pollution is associated with morbidity effects (asthma, bronchitis, *etc*.) and death. According to the WHO definition of health, all these outcomes are potentially relevant for HIA. The choice of studied health outcomes depends on the objectives of the HIA. Some assessments focus on mortality only, whereas others on several indicators, including mortality and morbidity (WHO working group, 2000).

The exposure-response function (which quantifies the change in the population health due to a given exposure) is identified to be the main source of uncertainty in an integrated assessment (Tainio, 2009). Levy and Spengler (2002) and Levy et al. (2007) concluded that dispersion uncertainties (exposure calculation) had only a minor impact on health effect estimates in comparison to exposure-response uncertainties.

Exposure-response functions are often derived based on epidemiological studies e.g. effect of air pollution on mortality rates. In general, studies that have used finer spatial resolution to relate population to air pollution levels tend to report higher mortality/morbidity impacts (Tainio, 2009). Therefore the literature recommends to use the most detailed exposure estimate available (e.g. for pollutants with high spatial variability this can be based on personal activity-based modelling or personal dosimetry) in epidemiological studies, assessing the health effects of air pollution.

A distinction has to be made among the various pollutants for which health impact relationship is known. Recently, the focus has been on air particulate matter, but other pollutants have also been studied. REVIHAAP and HRAPIE studies in charge of the WHO (to be published) are undertaking an extensive revision of the stat-of-the-art on pollutants, related health effects, dose-response functions (HEI 2013).

2.7 Indicators of health used in integrated assessment studies for air pollution

HIA studies use one or more indicators of health to express the change in population health status due to exposure to stressors, like air pollution. Most common indicator used is premature mortality, with different variations. Other common indicators involved are morbidly, life-expectancy, and recently more and more popular disability-adjusted life-years (DALY).

The selection of the indicator depends on the stressor studied, availability of data, computer resources, skills, and purpose of the study. For example, cost-benefit studies usually prefer to list all mortality and morbidity outcomes to compare all health benefits with all the costs of mitigation actions. Some other IA studies involving multiple stressors might require indicators that take into account age, or both mortality and morbidity effects.

The choice of indicators is driven by data availability, practicality and needs of the assessment. Therefore all of the indicators are state-of-the-art in certain conditions.

Previous discussion mainly focuses on mortality as hard endpoint. Other endpoints related to air pollution by particulate matter (PM2.5 and PM10) may be considered in HIA as well. Mortality will have largest impact relative to other endpoints when these are weighted against each other (for example DALY approach or monetarization of the health effects). Examples of common morbidity endpoints are: bronchitis in children < 18y, chronic bronchitis, asthma attacks, cardiovascular (CV) hospital admissions, cerebrovascular hospital admissions and respiratory hospital admissions, emergency visits for asthma & CV, Restricted Activity Days (RAD) *etc*. Monetization is another way to express health effects. However, monetization will be reviewed later on in Deliverable 2.5 and will be mentioned only briefly in this report.

2.7.1 Mortality

The "indicator "Mortality" measures the changes in the mortality rates due to exposure to environmental stressor(s). Mortality indicator has several different names, including, but not limited to, premature deaths, avoidable deaths, attributable cases of death, additional mortality, and death postponed. Common feature for this family of indicators is that the health effects are expressed as number of deaths. Results are expressed with sentences such as: "*The primary fine particulate matter emissions from Finland were estimated to be responsible for 209 (mean, 95% confidence interval 6-739) premature deaths in Finland*" (Tainio et al. 2010).

The mortality indicator has been criticized because the measure does not provide any information on how premature is the actual death (e.g. Brunekreef and Hoek, 2000; Rabl, 2003). Thus, the premature death does not distinguish between a case where death is advanced by one day from the situation of one year, or one decade. This might give misleading information in cases where the stressors impact different age groups. For example, stereotypical traffic accident fatality occurs for 20+ year old male while air pollution related lung cancer deaths occurs in much later age. Other indicators, such as years of life lost (YOLL) has been introduced because of the most basic criticism that deaths cannot be directly attributed to any stressor. Therefore mortality is mainly a conventional measure of health and it is widely used in IA studies because of its easy intelligibility and the availability of data.

2.7.2 Morbidity

Morbidity indicator estimates the changes in new or existing diseases in the target population. One stressor can cause several individual morbidity outcomes. For example, the Lopez et al. (2005) study used following morbidity indicators: chronic bronchitis, all respiratory causes, asthma, chronic obstructive pulmonary disease (COPD), pneumonia, all cardiovascular, congestive heart failure, ischemic heart disease, all respiratory causes, restricted activity days (RAD), minor restricted activity days, school absenteeism. Some of these, like pneumonia, are specific diseases while others are non-specific (hospital admissions and RADs).

Morbidity cases are commonly divided into incidence and prevalence. Incidence means new cases of disease in given period of time. For example, number of new pneumonia cases per year. Prevalence describes the proportion of population that has a particular disease. For example, 1% of target population has pneumonia due to air pollution. Both incidence and prevalence data have been used in IA studies.

2.7.3 Health perception (and well-being)

Health perception is individual's subjective assessment of his/her wellness and illness. Health perception has been used in some epidemiological studies but rarely in HIA studies to express health differences between scenarios or populations.

2.7.4 Life expectancy

Life-expectancy is a statistical measure of the average life span of a population. The life-expectancies are estimated with life-tables that express the probability of surviving over the next age interval (Miller and Hurley, 2003). In addition to life-expectancy, a number of other health measures can be estimated from a life-table (see YOLL).

The most common life-expectancy measure is the life-expectancy at birth (e.g. life-expectancy of birth is 82 years). Life-expectancy at birth for year 2008 is estimated by calculating hazard rates based on population and mortality data from the year 2008 and assuming that the hazard rates remain constant over the lifespan of the population. More sophisticated methods take into account the change in hazard rates over the time e.g. by adopting the mortality projections from WHO (Mathers and Loncar, 2006). Life-expectancy change due to stressors is calculated through the changes in the hazard rate.

In comparison to mortality, life-expectancy indicator takes better into account the age of the victim and expresses the results in more meaningful measure (life-expectancy). As a downside, the estimation of life-expectancy requires more data and expertise than mortality, and the communication of the life expectancy results is more problematic than mortality cases.

2.7.5 Years of life lost (YOLL)

Years of life lost (YOLL) indicator estimates the potential life years that were lost due to premature mortality. Other names for this indicator are e.g. years of potential life lost (YPLL) or potential years of life lost (PYLL). Calculation of YOLL varies from simple comparison of the age of death with the expected life expectancy of a person with that age, to multidimensional life table model that calculates YOLL, and other indicators. YOLL is also one of two components of disability-adjusted life-year (DALY, see next part).

The main advantage of YOLL in comparison to mortality indicator is that it takes into account age of victims, like life-expectancy indicator, but the calculation of YOLL can be simpler than running of a life-table model.

2.7.6 Disability-adjusted life-years (DALY)

Disability-adjusted life-year (DALY) is a measure of disease burden. The DALY indicator have been developed and applied especially in the Global Burden of Disease studies (Murray and Lopez 1997).

DALY has two components; YOLL (mortality effect) and years lived with disability (YLD) (morbidity effect). The YLD combines the morbidity with the duration of that morbidity and disability weight. Disability weight express the severity of disease with scale from 0 (no disease) to 1 (death). These are defined by a team of experts. DALY is the combination of

YLD and YOLL.

The main benefit of DALY is that it combines mortality and morbidity effect to one health indicator. This allows comparison of different kind of health effects, for example traffic injuries and lung cancers, with each other's. The DALYs can also be compared with the other disease burdens by comparing the results with the Global Burden of Disease studies (Murray et al. 2012). The main problem with DALY is that some morbidity outcomes, like hospital admissions, are not directly transferable to any specific diseases, and therefore all the common morbidity outcomes, associated with air pollution, cannot be expressed as DALYs.

2.7.7 Quality-adjusted life-years (QALY)

Quality-adjusted life-year (QALY) is another measure of disease burden and it also combines mortality and morbidity effects to one indicator. Pros and cons of QALY are similar than the ones for DALYs.

2.7.8 Years in healthy life (Healthy Life Years (HLY))

Years in healthy life is third measure of disease burden (Hyder et al. 1998). Just like DALY and QALY, it compares mortality with morbidity, with similar pros and cons (WHO 2010, Wilson et al., 2012)

2.7.9 Other

Other indicators could be useful, such as a registry of complaints or a panel of trained individuals to environmental smell.

3 Rationale of the Database structure for topic 3 (Health Impact Assessment)

The tool we used to collect information from air quality activities has been designed to reflect existing and implemented methodologies used to conduct HIA; whether they have been used for a research project, a planning activity or a case study.

Several research teams have developed methods to assess health consequences induced by air pollution and applied those methods in different case studies. Some of those are used for the assessment of air quality action plans or other interventions. We have based the design of the Database to be able to assess the extent of the use of those various methodologies.

The questionnaire is divided into closed and open-questions. Following the state-of-the-art,:

Approaches and scenario's

Time-series

Pollutants, exposure & health effects

Health impact relationships (values, population, …)

Indicators of health used in integrated assessment studies for air pollution

Open questions have been added in order to evaluate the difficulties and limitations of HIA in air quality action plans. They stress the availability of data on the health outcome, their causality to the air quality, the need for ethical committee approval or confidentiality procedures and the use of the state-of-the-art knowledge.

4 Current practices

4.1 General overview

The pilot phase concluded in the retrieval of 53 questionnaires. From those, basically, the main type of activities was Air Quality Plan and Research Projects. Most of the projects are conducted by Regional, Local authorities, some from institutional MS activities and only few of them are conducted by EU.

The activities reported are classified into 28 Air Quality Action Plans (AQP), 18 Research Projects (RP) and 7 other activities. Of these surveys return, 24 questionnaires responded to some questions in Topic 3 (HIA) and among those, 21 assessed thoroughly health impacts. Those having compiled HIA are respectively 10/28 Air Quality Action Plans, 11/18 Research Projects and 3/7 other activities. But, only 3 questionnaires have specifically expressed HIA as the main objective, respectively 2 for research projects and 1 for another activity (Figure 2). This reflects the fact that Integrated Assessment Models do not all necessarily include the health aspects.

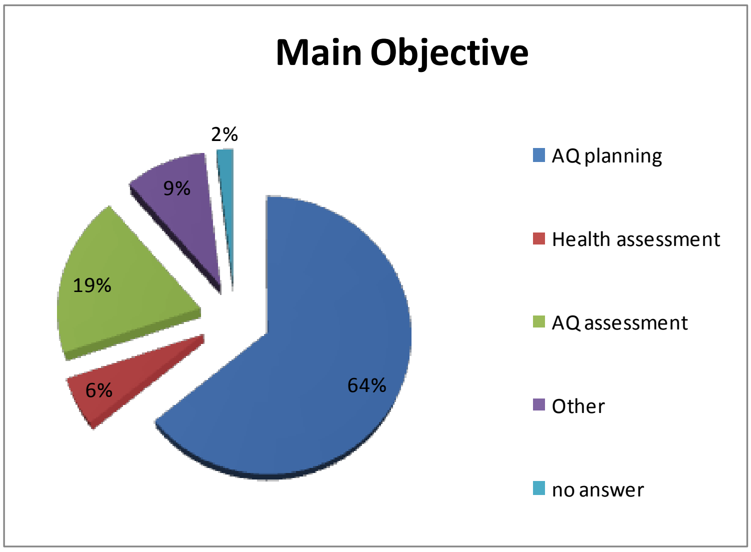

Figure 2: Main objective expressed in the compiled questionnaires

The questionnaire did not offer the widest scope of answers but from the filled questionnaires we can observe that a user-guide should accompany the tools as there is a common discrepancy between the described approaches and the answer “other” in other parts of the questionnaire.

4.2 Approach

The most common approach used is the predictive approach (9 times) and the retrospective approach (5 times), while the counterfactual approach had been answered 2 times and other 7 times. The “predictive approach” answer was the only one with several possibilities (scenario towards reference values or iterative decrease of exposure) and the responses are respectively 8 projects using reference values and one with an iterative decrease of exposure. The once who responded “other” did not find the adequate description for their activity.

Additional in-house knowledge on the activities compiled via the questionnaire signals problems in the answering and the adequacy of the questionnaire as some projects dealt with counterfactual approach using iterative decrease of exposure and reference values for instance. That option was not offered.

Nevertheless the need to develop a practical and clear user-guide including definitions of the terms and help to choose among the options is needed for next steps as there has been a common misunderstanding between predictive and counterfactual.

4.3 Time-series

Among all the activities, 10/25 provided a HIA focused on both short-time and long-term exposure to pollutants, all the other (14/25) except one focused on long term exposure for their HIA temporal resolution. There were 9 AQP and 7 of those focused on both long and short term exposure.

The modelling scheme used for HIA could be based on different data sets. Emission data and exposure data or individual exposure are among the data sets used in the litterature. Emission data would reflect an intervention on the emission sources whether exposure data would account for assessment of air quality. Measured or modeled exposure data target currently large population groups. Individual exposure sets of data are currently not as commonly used in HIA.

4.4 Pollutants, exposure and health effects

The most frequent air pollutants included in the health impact assessments are the “traditional” pollutants, such as particles (PM10 and PM2.5), nitrogen oxides (NO_x) and ozone (O_3) (Figure 3). Notwithstanding the high percentage of “other” and “no answer” results, PM2,5 and PM10 are the most addressed pollutants, followed by ozone. For 19 amongst the 22 collected questionnaires reporting information on HIA, several pollutants were considered at the same time. Table 1 indicates the nature of pollutants that were reported for HIA with their respective frequency.

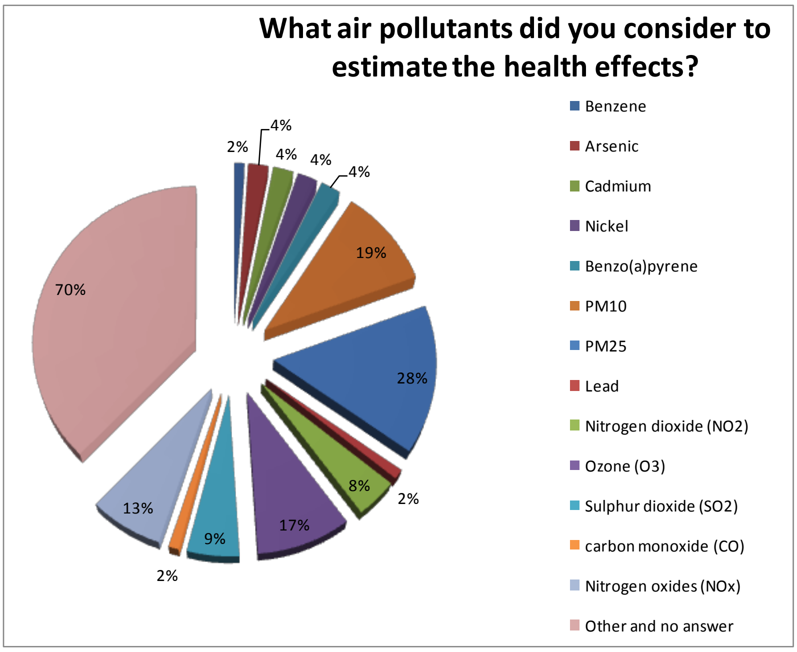

Figure 3: Air pollutants used for HIA.

Pollutants	PM2.5	PM10	O_3	NO_x	NO_2	SO_2	C_6H_6	BaP	As Cd Ni	Others
Frequency	14	10	8	6	3	4	1	1	1	2

Table 1: Distribution and frequency of pollutants reported for HIA in 19 questionnaires.

However, if we compare Air Quality Action Plan and Research projects/activities, other pollutants such heavy metals (arsenic, nickel, cadmium and lead) are considered besides the “traditional” pollutants monitored for human health effects estimation. (Figure 4)

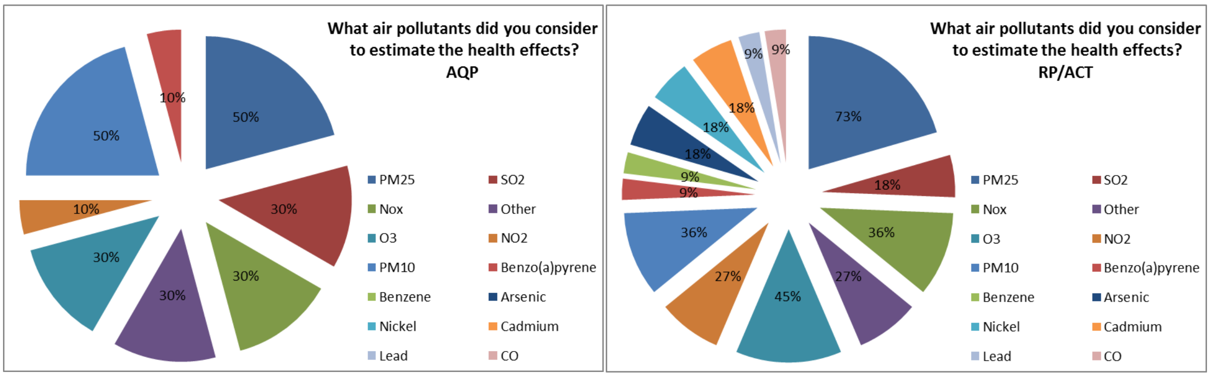

Figure 4: Air pollutants used in HIA for Air Quality Plans (AQP) and for Research projects (RP/ACT)

The exposure indicators, for both Air Quality Plans and Research projects/activities, were calculated based on emissions, air quality monitored data and air quality modeled data (Figure 5). Additionally, exposure indicators based on individual exposure data were also used in the scope of Research projects/activities.

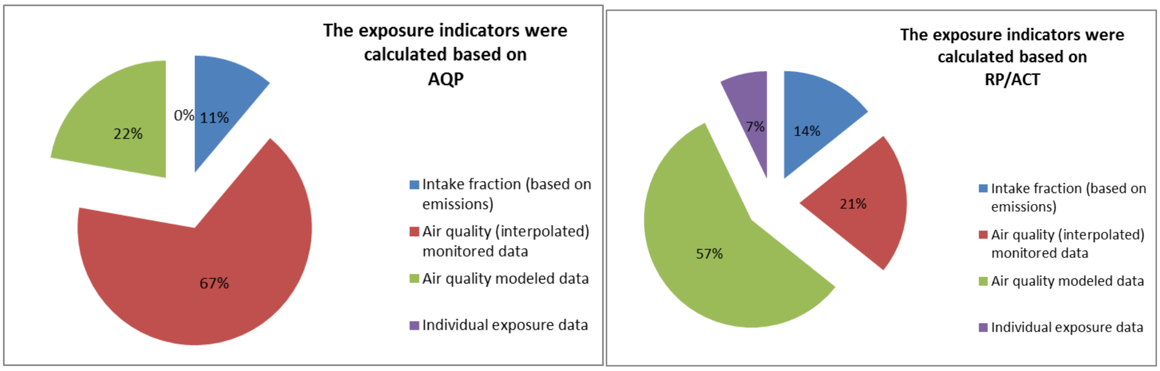

Figure 5: Distribution of the calculation for exposure indicators in Air Quality Plans (AQP) and Research projects (RP/ACT)

The spatial resolution considered for population and concentration estimation is usually the same (Table 2). For the particular cases where used resolution was different, AQP implied a less detailed resolution data and Research projects/activities a more detailed exposure analysis sub-model. For air quality models the resolution of a dispersion model is important for estimating exposure (Thunis et al., 2007). Usually a difference is made between national- or regional-scale and urban-scale models, based on spatial resolution. Regional-scale dispersion models predict well air pollutant concentrations far away from emission sources, however dispersion models with sparse resolution may underestimate exposure near emission sources, which may also give an underestimate in HIA when applied. This is important for low emission height sources, emitting pollutants with high spatial variability, e.g. from traffic (Tainio, 2009).

Urban-scale dispersion models are used for smaller geographical areas, e.g. cities. They are able to evaluate spatial variation of air pollutants over short distances. However, long-range transported air pollutants should also be taken into account and these are integrated into the urban-scale dispersion models by a variety of strategies.

The temporal resolution used for concentration data differs between the two types of activities (Table 2). 50% of the assessed Air quality plans use daily temporal resolution, 25% hourly and 25% annual. Research projects/activities did not use daily resolution and 50% are based on annual data, 30% hourly and 20% use other type of temporal resolution.

Considered population number	< 1 million	1 to 10 million	> 10 million		
	8 (36 %)	10 (46 %)	4 (18 %)		
Population subgroup	No	Age	Age + gender		
	18 (82 %)	3 (13,5 %)	1 (4,5 %)		
Spatial resolution AQ vs population	Same resolution	Lower population resolution	Higher population resolution		
	16 (73 %)	4 (18 %)	2 (9 %)		
Time resolution AQ data	Annual	Daily	Hourly		
	10 (45 %)	5 (23 %)	7 (32 %)		
Assessment of exposure	Intake fraction	Modeled	Monitored	Both Mon+Mod	Individual exposure
	1 (5 %)	14 (64 %)	4 (18 %)	2 (9 %)	1 (4 %)

Table 2: Statistical overview of parameters implemented concerning the exposure assessment.

In the case where monitored concentration levels were used for the assessment of exposure, the following station sites were considered (Table 3).

Type of station sites	Number of models
Urban background	1
Urban + sub-urban background	2
Traffic + urban + sub-urban background	1
Urban + sub-urban + rural background	1
Industrial + urban + sub-urban + rural background	1

Table 3: Distribution of the types of monitoring station used for the exposure assessment

4.5 Health indicators

Approximately half of the activities (25) had considered health effect of pollutants and 19 had answered to the question: "*What health indicators were used?*".

Approximately 20% of the AQP that underwent HIA considered a sub-group based on the age of the population. Research projects/activities, also focused on the sub-groups gender and on other variables, beside age (Figure 6).

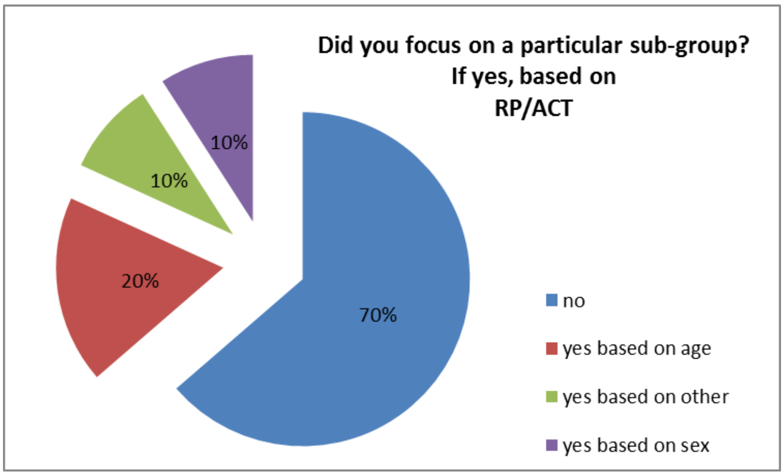

Figure 6: Focus on specific sub-groups in the Research Projects

Most common indicator used was premature mortality, with different variations. Other common indicators involved morbidly, life-expectancy, and recently more and more popular disability-adjusted life-year (DALY). Table 4 shows the distribution of the different indicators used in the 19 questionnaires, as only 19 studies answered for that part of the questionnaire.

Indicator	#
Mortality	7
Morbidity	9
Health perception	1
Life expectancy	3
Years of life lost (YLL)	5
DALY	5
QALY	0
Years in health life	1
Others	2
Total	33

Table 4: Health indicators used in the studied activities.

Morbidity was the most common indicator, used by almost half of the studies. Second most popular indicator was mortality. QALY was the only indicator that had not been used in any of the studies. Two studies had also used other indicators. Unfortunately there was no mention on what kind of indicators they were using.

Although morbidity was the most popular single indicator, mortality driven indicators (additional mortality, YOLL, life-expectancy) were used in 11 studies. From the 8 studies that were not using additional mortality, YOLL or life-expectancy, three studies used DALYs and one study health perception. Both of these indicators combine mortality with morbidity so it's likely that these studies were also estimating mortality impact. Only two studies did not consider mortality impact.

Most of the studies (12) had reported only one indicator of health. From the remaining 7 studies, one study reported 5 different indicators and others 2 or 3.

4.6 Monetization

From 53 studies, 22 had answered to question "Were health effects monetized?". From these studies, 9 had answered yes. From indicators point of view interesting results here is that from those 9 studies that had monetized the health effects, 6 were using morbidity indicator. From the three studies that did not consider morbidity indicator, one was using DALYs (that has morbidity component) and one life-expectancy indicator. One study, that had monetized health effects, did not report the health indicator.

4.7 Open questions

The analysis of the open questions and the comments collected gives another insight on HIA implementation. The following reasons in relation with the exposure assessment are considered leading to major uncertainties in the HIA:

- Sources of emission or emission inventories
- Poor population exposure data, in particular for daily exposure values (3 comments)
    - Indoor exposure contribution not taken into account (2 comments) people spend more than 80% of the time in indoor environment, so the interpretation of the result and integration of this kind of aspect should be more investigated in order to minimize bias of data interpretation.
- Lack of dynamic dimension in exposure evaluation (2 comments)

For example, an activity-based approach can provide more realistic estimate of the change in exposure from travel behavior, and bridge the gap between transport and health policy (Dhondt, 2012).

- Poor exposure-response functions (2 comments)
- Air quality levels are needed temporally and spatially distributed with the proper resolution for agglomerations (urban areas).
- Individual and population exposure studies are needed for a better link between air quality data and health effects.
- Procedures to evaluate HIA results are needed.
- Real need to further explore the "complete individual exposure to air pollution". With "complete" we mean as well indoor as outdoor air pollution. With "individual" we mean monitoring air quality at the level of the person itself, using portable-and-easy to wear monitors.
- Methodology to take into account other health data (asthma consultations, emergency consultations...)

What is the consideration of health within the government decision-making processes, which may or may not include HIA in the processes? How HIA can be included among other sectors? are ever remaining questions.

5 Limitations of current assessment methods

5.1 Compare state-of-the-art & results from database

Only a few of the collected projects and activities include HIA. But among those implementing HIA, most studies use current state of the art methodology as they refer to WHO guidelines. Some of the investigators think that they use the state of the art tools to assess impact of air pollution on human health, because they referred to a specific method (CAFÉ estimates, EU limit value, etc.). Half of the studies carried out were executed in the framework of economic assessment. The methodology used aimed to determinate how much money could be saved or lost if prevention approaches was to be taken. Somehow prevention costs less than treatment or remediation (polluter pay principle) (REF).

At the 2013 HEI workshop

(http://www.healtheffects.org/Workshops/Brussels2013/brussels2013-agenda.htm) held in Brussels, recommendation was given to focus more on traffic exposure (TRANSPHORM project), develop EU harmonised traffic indicators for exposure (e.g. harmonised black carbon indicator; Janssen et al., 2011) and not consider all PM constituents to have the same toxicity (http://www.healtheffects.org/Workshops/Brussels2013/Presentations/Vedal.pdf).

Generally, projects are focused on long-term exposure that has much greater public health impact. Some acute effects are included in chronic effects, but not all short-term health impacts are included in long-term impacts, therefore, short-term impact on mortality might be underestimated.

Researchers have shown that, at a population level, no threshold of effect can be identified for the common air pollutants and thus one can expect an impact in some individuals even at low levels of exposure (Kelly, 2012). In general for PM2.5 no threshold is used and the exposure-response relationship for mortality is not significantly different from linear. More attention may be given to the inclusion of sensitivity analysis (e.g. including long-term exposure effects for ozone).

5.2 . Knowledge implemented / not implemented in HIA

The analysis of the activities from the answers to the questionnaires shows that the choice of indicator is more often driven by practicality and needs of the assessment than by any other reason. Therefore all of the indicators, presented earlier in this document, are state-of-the art in certain conditions. To be able to fully review the studies, the purposes and use of the studies would need to be known more detailed than is possible in this review. Thus, the state-of-the-art of different indicators is not driven by the selection of indicator itself but the data that is used to calculate the indicator and the use of the indicator.

6 Key areas for future research and innovations

The following research needs in relation with the exposure assessment were considered to be important for HIA:

- The need to further explore the "complete individual exposure to air pollution" is strongly felt. With "complete”, as well indoor as outdoor air pollution and a period of 24h/24h is meant. With "individual", monitoring the air quality at the level of the person itself, using portable-and-easy to wear monitors is meant. These two factors will eventually result in a more complete view on the individual exposure to pollutants. If this could be combined with human biomonitoring, i.e. measuring the concentration of a certain pollutant or one of its by-products in the human body, this would be a real added value to our current knowledge concerning the impact of air pollution on human health.
- The distance to relevant traffic lines is known to have a crucial effect on population exposure and health effects and should be further investigated.
- The dynamic dimension of individual exposure and its integration of successive environments such as indoor and outdoor, should be further investigated in order to come to a better understanding of the relationship between microenvironments, activities and lifestyle and human exposure.
- Individual and population exposure studies are needed for a better understanding of

the link between air quality levels, exposure, individual doses and health effects.
- More detailed modelling tools are needed to assess the population exposure to pollutants, not considering simple static maps of population and pollution, but dynamic ones (i.e. considering hour-by-hour where the population is living/working, depending on age, gender, activity... and modelling air quality maps with the same level of detail, to compute the real population exposure).

Additionally, among the open questions, several related to further needs in research as the following:

- Move from air pollution levels to exposure and to dose
- Air quality levels are needed temporally and spatially distributed with the proper resolution for agglomerations (urban areas). Individual and population exposure studies are needed for a better link between air quality data and health effects. In that idea, cohort studies with personal dosimetry to re-evaluate long term relative risks and a methodology to take into account other health data (asthma consultations, emergency consultations...)
- Procedures to evaluate HIA results are needed.
- Coupling AQ / Energy infrastructure model with other health impact tools
- Researchon other pollutants such as black carbon (EC/OC) impacts
- More methods to combine different kind of health effects from different pollutants.
- Combination High Resolution air quality with dynamic exposure

7 Contribution to the AQD revision

7.1 Impact of personal exposure to multiple pollutants

For assessing accurately health effects of air pollution, detailed exposure estimates need to be available. Aggregating monitored data collected by different monitoring stations or concentrations measured at central monitoring stations or proximity measures seems not to reflect the personal exposure. Estimating detailed personal exposure to air pollutants should be a topic more addressed. Indeed, individual exposure studies should include parameters affecting their exposure (cultural, socioeconomic, ethnic, *etc*.). Although most health outcomes are not confined to a single pollutant, studies typically focus on the risks of single pollutants and do not consider the mixture of pollutants. There is a clear need to develop methods for conducting evaluation and management the effect of the air pollution with multi-pollutant approach. However, it should also be remembered that particulate matter (PM) air pollution is already by itself a mixture of solid and liquid elements and not a single pollutant.

Epidemiological analyses were critically sensitive to the exposure assignment model used. Health impact assessment needs to consider the simultaneous exposure to multiple pollutants and particularly vulnerable groups of population. Usually, interaction among these different pollutants and the mixture of these with natural pollutant of the environment are not included. Furthermore, epidemiological studies analyzing the potential HIA in the future, are based on health outcomes measured in the past, which is combined with a given exposure to a given pollutant, whereas more events may occur at any time, namely, due to changing air quality and to the characteristic of the population at the study period.

To fully assess the health impact, we must take a multiple pollutant exposure approach and consider also that air pollution exposure has both physical and psychological effects; even these latter dimension is less documented and is more difficult to measure, subjective indicators constitute an appropriate alternative.

8 Conclusions & Summary

The implementation of HIA depends on a complex network of actors and agencies, ranging from engineers to industrials, urban planners or other sectors. The translation of health aspect into a policy framework, basically, requires the sustained collaboration between scientists, health professionals, the complex of policy making and the public.

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