The use of Health Impact Assessment tools in European Cities

A guide to support policy towards cleaner air and improvement of citizens' health

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Preface

Context

In May 2016, the Urban Agenda for the European Union was established in the Pact of Amsterdam in order to jointly improve the quality of life of urban citizens in Europe. In order to achieve this, Member States, cities, the European Commission, and their networks are working together. To read more about this partnership and its priorities visit https://ec.europa.eu/futurium/en/urban-agenda.

Priority Air Quality

One of the twelve priorities to put high on the agenda of the European Commission is air quality in cities, which resulted in the Partnership for Air Quality (PAQ). The PAQ strives to propose action plans to improve regulation, funding and knowledge of and about reduction of air pollution. To read more about the PAQ visit https://ec.europa.eu/futurium/en/air-quality. In the context of the PAQ it has been evaluated what the obstacles are in the regulation, funding, and knowledge to improve air quality. Drawing on the evidence gathered to find concrete solutions to the issues identified, a series of actions have been developed. These findings and actions are presented in an action plan (Urban Agenda for the EU, 2017).This report is a section of the action plans for better knowledge: Action N°4 – Better Focus on the Protection and on the Improvement of Citizens' Health. Current policy on air quality is mostly focused on avoidance of exceeding limit values. The aim of the current report is to propose a method to quantify the effects of air pollution on citizens' health to facilitate a shift towards policy where health is a key feature to take into account.

Goal/approach

To contribute to Action N°4 and facilitate a shift towards policy where health is a key feature to take into account, health impact assessment tools will be reviewed in the context of European urban air quality. European cities are the focus, but this is not a restriction for other stakeholders to use the tool. In any case, the results of this project can be used as an objective measure to support policy that considers improvement of public health.

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Abbreviations

ALRI	Acute Lower Respiratory Infection
BC	Black Carbon
BOD	Burden of Disease
C_0	Counterfactual Value
CI	Confidence Interval
COPD	Chronic Obstructive Pulmonary Disease
COMEAP	Committee on the Medical Effects of Air Pollution
CRF	Concentration-Response Function
CVD	Cardiovascular disease
DALY	Disability-Adjusted Life Year; metric for indicating burden of disease based on the combination of years of life lost and years lost due to disability (DALY=YLL+YLD)
DW	Disability Weight; weight factor indicating the severity of a disease
EC	Elemental Carbon
EEA	European Environmental Agency
EU	European Union
FAIRMODE	Forum for air quality modelling in Europe
GBD	Global Burden of Disease (WHO assessment)
HIA	Health Impact Assessment
HRAPIE	Health Risks of Air Pollution in Europe Project
IHD	Ischemic Heart Disease
Incidence	The incidence is the number of new cases of a certain medical condition per population at risk in a given time period
LE	Life Expectancy
LC	Lung Cancer
MRAD	Minor Restricted Activity Day
NO_2	Nitrogen Dioxide
O_3	Ozone
PM	Particulate Matter
PM_{10}	Particulate Matter with an aerodynamic diameter smaller than 10 μm
$PM_{2.5}$	Particulate Matter with an aerodynamic diameter smaller than 2.5 μm
PAQ	Partnership for Air Quality
PATY	Pollution and the Young study
Prevalence	The prevalence is the number of cases of a certain medical condition at one moment in time
PWEL	Population-Weighted Exposure Level
RAD	Restricted Activity Day
REVIHAAP	Review of Evidence on Health Aspects of Air Pollution Project
RR	Relative Risk; describes the likelihood of adverse health effects occurring in high exposed populations compared to low exposed populations
SHERPA	Screening for High Emission Reduction Potential on Air
WHO	World Health Organization
WHO AQG	World Health Organization Air Quality Guidelines
YLD	Years Lost due to Disability; a component of DALYs
YLL	Years of Life Lost; a component of DALYs
Σ	Sum
$\mu g/m^3$	Microgram(s) per cubic meter

1. Introduction

1.1 Air pollution and health

With approximately two thirds of the European population living in cities, it is of great importance to keep improving the livability of urban areas. A large improvement can be achieved by tackling environmental risk factors, since these factors comprise a great contribution to the total global burden of disease (GBD). Of the environmental risk factors, air pollution causes the greatest disease burden with over 400,000 premature deaths in Europe per year (Forouzanfar *et al.*, 2016; EEA, 2017). Consequently, an effective way for improvement is implementing air quality policy. It has been proven that intervention often leads to a reduction in public health risks (Henschel *et al.*, 2012). The effectiveness of these interventions can be assessed by so-called called air pollution accountability studies (Henneman *et al.*, 2017). By assessing the effects of past intervention, air pollution accountability works as a framework that can be used in future implementation of air quality policy.

1.2 Air pollution and their sources

Air quality is defined by a complex mixture of pollutants. This complexity makes it hard to attribute the observed health effects to one pollutant; or avoid double counting of health risks. The air pollutants that have been documented for having most influence on adverse health effects in humans are particulate matter (PM), nitrogen dioxide (NO_2), and ground-level ozone (O_3) (WHO, 2013a). PM consists of a mixture of chemicals and can be subdivided in PM with a diameter smaller than 10 µm (PM_{10}) and 2.5 µm ($PM_{2.5}$). One of these chemicals is black carbon (BC, when measured with optical methods) or elemental carbon (EC, when measured with thermal methods), which are causally associated with a risk for human health (Janssen *et al.*, 2011). The smaller the particles, the lower in the respiratory system infiltration takes place. In this way, the smallest particles can eventually enter the bloodstream causing health risks to extra-pulmonary organs such as the heart and the brain. It is therefore of value to take BC/EC as an additional air pollutant next to PM_{10} and $PM_{2.5}$ when defining the health risks associated with air pollution. Ground-level O3 is not directly emitted into the atmosphere. Instead, it is formed from chemical reactions in the presence of sunlight, following emissions of precursor gases, mainly NOx, and volatile organic compounds (VOC).Ozone concentrations strongly depend on the tropospheric background levels; emission reductions at the local scale have limited impact on the local ozone levels. Highest concentrations are found in rural areas, since in urban areas O_3 is depleted in the presence of NO, by forming NO_2 and O_2 (EEA, 2017). Because it is not possible to directly influence the formation of O_3, it is chosen to not take into account O_3 in the current report. The present research will focus on the health risks associated with PM_{10}, $PM_{2.5}$, EC, and NO_2.

In order to make effective air quality policy, the spatial and sectoral allocation of pollutants is important (Figure 1). Air pollution in cities does not only come from local sources, but also from external sources outside of the cities such as the industry and the agricultural sector. This means that the smaller the percentage of total mass of air pollutants contributed by the city, the smaller the effects of local air quality policy. Figure 1 shows, as an example, the contribution of different emission sources of $PM_{2.5}$ for Utrecht (NL, Figure 1A) and Milan (IT, Figure 1B). Both figures are produced by the SHERPA project (Thunis *et al.*, 2017). The sectoral allocation is subdivided into transport, industry, agriculture, residential, other, natural, and external sources. The spatial allocation is subdivided from the smallest region (city) to transboundary sources. These allocations give insight in where policy should focus on in order to achieve the most health benefit. Although, it should be taken into account that sectors with the largest contribution to air pollution in theory do not always practically have the largest potential of reducing air pollution. In Utrecht local policy can achieve the most reduction in air pollution by reducing traffic (in SHERPA referred to as transport). In Milan, also reducing emission from the residential sources (such as cooking and heating stoves and combustion in fireplaces) can be of great influence. These figures also indicate that local policy alone will not always reduce a great proportion of the total concentrations of $PM_{2.5}$. Sources outside the cities are causing high background concentrations. Especially cities with a relatively small local contribution to the total concentration should also focus on national and international policy, when trying to reduce air pollution (Thunis *et al.*, 2017).

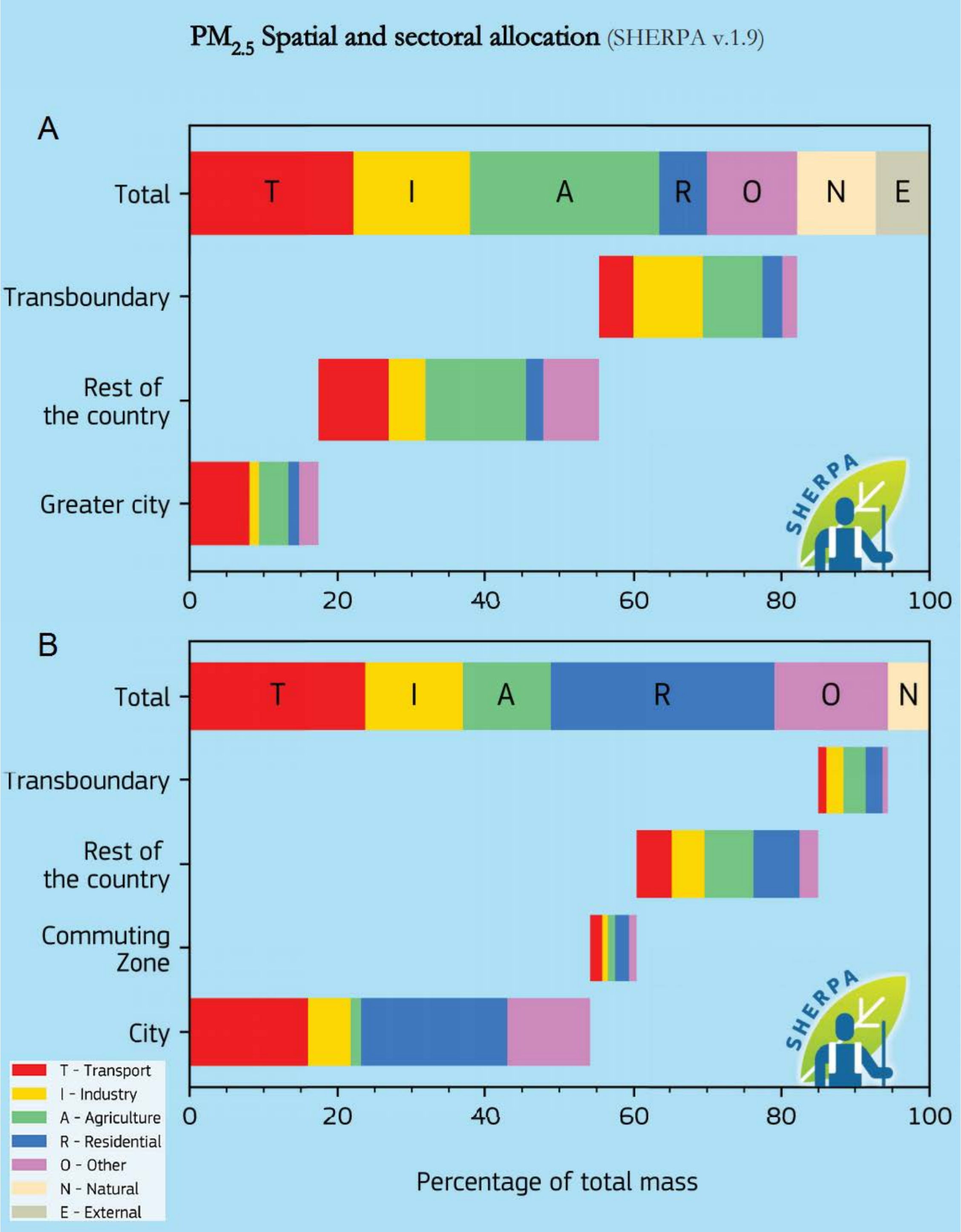

Figure 1. Spatial and sectoral allocation of $PM_{2.5}$ in Utrecht (A) and Milan (B). This figure shows the contributing percentage of total mass for the sources transport, industry, agriculture, residential, other, natural, and external. In addition, the contribution of the city, rest of the country, and transboundary are shown. Source: SHERPA Urban $PM_{2.5}$ Atlas.

The previously described different components of air pollution are emitted by different sectoral sources. BC/EC and NO_2 are mainly emitted by local sources such as traffic, fossil fuel combustion, industrial processes and domestic heating, leading to relatively low contribution of non-local sources compared to PM_{10} and $PM_{2.5}$ (Gemeente Utrecht, 2017). The relative high background PM_{10} and $PM_{2.5}$ concentrations can be explained by their higher contribution from sources outside city borders, such as natural sources (e.g. soil, dust, sea salt, and bioaerosols), industrial energy use and processes, and agriculture (EEA, 2017). Agricultural ammonia emissions are influencing the formation in the air of secondary particulates such as ammonium nitrate that forms a major part of the PM concentrations in North Western Europe. Hence, local policy is more likely to be effective when targeting BC/EC and NO_2.

1.3 Air quality policy and the focus on citizens' health

The European Commission has established Air Quality Directives as an instrument to reduce air pollution. As a result, air quality has been improved. Despite this, a significant proportion of the population in urban areas is being exposed to pollutant concentrations above the EU limit values (EEA, 2017). This proportion becomes even greater when the World Health Organization Air Quality Guidelines (WHO AQG) are applied, which have their focus chiefly on the protection of public health. These guidelines are of great support for most governing authorities, but meeting the guidelines does not imply that health risks do not occur. Until now, there is no scientific evidence to assume a safe level for any pollutant. Therefore, intervention on local, national, European and global level that focuses on public health instead of the exceedance of limit values is needed to improve air quality and decrease its share in the burden of disease.

A way to focus on public health is to use Health Impact Assessment (HIA). HIA is a method for quantifying the impact of air pollution on citizens' health. In the next chapters HIA will be further explained.

Depending on the available data, different questions can be answered with HIA:

- In the current situation, what are the public health risks of air pollution concentrations on the population?
- What are the health benefits of a certain policy implementation?
- Which air quality measures will result in the largest improvement of public health?

Both short-term and long-term negative health risks have been associated with air pollution. These impacts vary from effects on morbidity (such as asthma symptoms and hospitalizations) to increased mortality (WHO, 2013b). These effects have been reviewed in the Review of Evidence on Health Aspects of Air Pollution Project (REVIHAAP, WHO, 2013a). As a result, the Health Risks of Air Pollution in Europe Project (HRAPIE, WHO, 2013b) contains recommendations about how this evidence can be used in HIA in Europe. More information about the health risks of air pollution will be described in the following chapter.

In order to make HIA feasible, several HIA tools have been developed. HIA tools are models in which the user inserts data (e.g. pollutant concentrations, population characteristics, baseline incidences and concentration-response functions (CRFs). Subsequently, the burden of disease due to air pollution is calculated. These health risks can be calculated for a situation at one moment in time, a difference between the current and future situations or a difference between policy scenarios (i.e. health benefit or loss). This provides the opportunity to evaluate past implemented interventions or model the expected health benefit of possible future interventions. This is especially useful to create support for interventions that are being experienced to be 'inconvenient', such as low emission zones, building restrictions or biomass burning restrictions. Using HIA tools and thus being able to communicate the health risks associated with situations raises public awareness of poor air quality and connects governing authorities with scientific research throughout the regulatory process (Pennell *et al.*, 2013). In this way, HIA tools function as an instrument to enhance the use of scientific evidence when determining public health risks. Besides, communication of the urge of reducing air pollution to the public becomes more easy.

Unfortunately, HIA tools are not always used even though the results might lead to a better understanding of the effects of air pollution and to the promotion of clean air policy. The obstacle of using HIA tools often arises from a lack of understanding of the tool and/or the lack of clear instructions (S. C. van der Zee, personal communication, April 23, 2018). It is desirable to investigate and create a way to make HIA more prominent in air quality policy regulated by municipalities of European cities. The current project is focused on a pragmatic approach on the use of HIA tools in European cities. The goal is to create a package including an uncomplicated HIA tool with clear instructions to be implemented by as many institutions as possible throughout regulatory processes. By creating a tool package that is applicable to calculate the health benefit of certain intervention, municipalities could present objective results to support air quality policy.

2. Health Impact Assessment

2.1 Data collection

Depending on data availability in the region that is being studied, the accuracy of the data may differ. For the most accurate results, the data represents exactly the situation of the population. Unfortunately, this data is not available in every city. Because it is still important to carry out an HIA to screen policy strategies (be it with a larger uncertainty margin), the following headings will explain the possibilities for data input ranging from the optimal to the minimum required to apply the tool. The minimum required will be explained with the notion of the importance to support clean air policy by carrying out HIA, even in regions with poor data availability.

2.1.1 Population data

The population characteristics are of importance for HIA, because most health indicators are exclusively applicable to a specific age group. It is thus of relevance what the proportion of the age group of interest is in relation to the total population that is being studied. In the ideal situation, the number of people per age (groups of 1 year) is used of the population in the region that is being researched.

If the population data is not available for the specific region, it is optional to take the age structure of a geographically comparable region. This can for example be the whole country or a neighboring country.

If age structure data of the population of interest is available, but only for larger age groups (e.g. groups of 5 years), this can be used. Depending on the properties of the tool, the age structure data can be entered in age groups of 5 years, or the user has to simply divide the numbers by five and inserting these fractions for every mid-year population. Though, equally dividing the group of 5 years from 0-4 years old presumably leads to an underestimation of the attributable cases of post-neonatal deaths (1-12 months old) (HRAPIE, 2013b). This is because usually the death rate is higher at the age of 0-12 months compared to the years after.

The previous population data complies for HIA calculations for all morbidity health indicators and all-cause and cause-specific mortality. If the reduction in life expectancy is being calculated by doing life table calculations, it is required to enter data about the number of deaths in the population, or simply the age-specific death rate. This data should correspond to the age structure used in the assessment.

2.1.2 Air pollution exposure data

When calculating the health impact of air pollutants, exposure data is needed. Depending on data availability in the region that is being studied, the accuracy of the concentration data may differ. For instance, some regions only have data available from measurement points from fixed monitor sites. Other regions also model the concentration levels. Based on these concentrations it is possible to calculate the population-weighted exposure level (PWEL) for a city or neighborhood is used. The PWEL gives the most accurate exposure, because the pollutant concentrations weigh proportionally to the number of people that are being exposed. The PWEL can be calculated as follows:

$$\mathrm{PWEL} = \frac{(pop1 * exp1)\ +\ (pop2 * exp2)\ +\ (pop3 * exp3)\ +\ \dots}{\sum\ pop1, pop2, pop3, \dots}$$

where *pop* is the number of people and *exp* is the average concentration of the pollutant in µg/m^3 in a city, neighborhood, street, or grid.

However, because PM_{10} and $PM_{2.5}$ do not show a high spatial variability within cities, concentrations observed at monitoring stations which are not directly influenced by local sources like traffic or industry, will be representative for citizens' exposure. NO_2 and EC show higher spatial variability within cities. Therefore, for these pollutants modelled concentrations (based on traffic data) are preferred. Nevertheless, if NO_2 and EC concentrations are only available from representative (urban background) measuring sites, this data can be used to conduct health impact assessment.

If only the concentration of PM_{10} or $PM_{2.5}$ is known, the missing value can be calculated by using a conversion factor specific for your city (generally between 0.4 and 0.8). If this conversion factor is not available, the European urban average of 0.65 can be used ($PM_{2.5}=0.65*PM_{10}$ or $PM_{10}=1.54*PM_{2.5}$) (De Leeuw & Horálek, 2009).

If no concentration data is available in the region that is being studied, online databases can be used. For instance, the WHO Global Ambient Air Quality Database (http://www.who.int/airpollution/data/cities/en/) contains annual mean concentrations of PM_{10} and $PM_{2.5}$ in most European cities.

The local concentrations can be calculated with air dispersion models using emission inventory data as input. Model parameters can be calibrated with available monitoring results.

The EU Member States are required to deliver up-to-date concentration data of the different pollutants and have to communicate this to the public. If EU limit values are not met, the Member States are obliged to inform the public about the current state of air pollution and the actions that are going to be taken. The European Environment Agency (EEA) reports the provided data via several instruments, such as the annual “Air Quality in Europe” report and the public Air Quality e-reporting database. The Forum for Air quality Modelling (FAIRMODE) can be consulted for information on how to conduct good air quality modelling. The FAIRMODE networks’ aim is to promote harmonization of good model application and share knowledge with the EU Member States. Besides, the FAIRMODE has its focus on application under the European Air Quality Directives and other policy-related applications.

2.1.3 The counterfactual value of air pollution

The counterfactual value (C_0, sometimes referred to as cut-off level or no-effect level) is the concentration level under which no health effects are being calculated in HIA. The reason to assume a C_0 can be based of different arguments, depending on the question being assessed. This argument can for example be the limit values of the EU or WHO, the lowest concentration with which health risks have been associated in epidemiological studies, or the natural background level of pollutants present in the air.

In the context of the project of the current report, a C_0 of 2.5 µg/m^3 is recommended for HIA of $PM_{2.5}$. The Clean Air Package (EC, 2013) modelled the anthropogenic contribution to $PM_{2.5}$ and estimated a natural European background concentration of 2.5 µg/m^3. This is in line with the lowest measured concentration in populated areas (Horálek *et al.*, 2018). The GBD 2013-study (GBD, 2013 of Burnett *et al.*, 2014) calculated health impacts from concentration of 5.8-8.8 µg/m^3. In the GBD 2015-study (GBD 2015 risk factor collaborators, 2016) this was updated to a lower value of 2.4-5.9 µg/m^3, with the lower boundaries corresponding to the previous mentioned 2.5 µg/m^3. Besides, a Canadian study associated cardiovascular mortality with $PM_{2.5}$ concentrations of as low as 2 µg/m^3 (Crouse *et al.*, 2012).

For PM_{10} a C_0 is recommended based on the $PM_{2.5}/PM_{10}$ ratio of 0.65, e.g. 3.9 µg/m^3 for the default ratio of 0.65 (De Leeuw & Horálek, 2009).

For EC a C_0 of 0.3 µg/m^3, because this is approximately 1/10 of the C_0 of 2.5 µg/m^3.

For NO_2 a C_0 of 5 µg/m^3 is recommended. Health risks have been associated with minimum concentrations of 5-10 µg/m^3 (Raaschou-Nielsen *et al.*, 2012, Carey *et al.*, 2013). The COMEAP has also recommended a $C_0(NO_2)$ of 5 µg/m^3 (COMEAP, 2015).

2.1.4 Incidence rates

To quantify the share in burden of disease due to exposure to a specific air pollutant on health outcomes, the baseline incidence rates of the health indicator is needed. The incidence rate is the number of new cases of a certain medical condition per population at risk in a given time period. To carry out a HIA that most accurately describes the situation of the population of interest, the incidence rates of this population should be taken. Municipalities often do not have records of these incidence rates. If this is the case, the incidence rates of a comparable region should be taken. This often is country specific data, which can be found for European countries in the online WHO Health for All database (https://gateway.euro.who.int/en/hfa-explorer/).

2.2 Scientific evidence of health risks associated with air pollution exposure

In order to calculate the health risks associated with air pollution, epidemiological studies have estimated the relative risk (RR) of adverse health outcomes corresponding to exposure to various air pollutants (e.g. post-neonatal mortality, bronchitis in children or adults, hospitalizations, lung cancer, premature death). The RRs describe the likelihood of adverse health effects occurring in either high or low exposed populations. The RRs are estimated based on concentration-response functions (CRFs), which measure the relationship between the variation in pollutant exposure and the occurrence of the health indicator. Most epidemiological studies are carried out in North America and Europe. Therefore, the RRs are applicable to populations in these regions. Meta-analyses of these epidemiological studies provide reliable RR estimates by combining the results of multiple studies. Meta-analysis are ideally based on systematic reviews that give quantitative (e.g. the size of the cohort) and qualitative (e.g. the quality of the analysis, biases) weights to studies.

It is important to note that HIA is often carried out for a selection of health effects, and is not an estimation of the total health impact. To do health impact assessment, the most recent epidemiological evidence should be used. Hence, HIA tools should be regularly updated to remain accurate.

2.2.1 Evidence for mortality

$PM_{2.5}$, PM_{10}, NO_2 and BC/EC have all been associated with all (natural) cause mortality (WHO, 2013b; Hoek *et al.*, 2013, Table 1). The effects of single air pollutants on similar health indicators (in this case all-cause mortality) have been a point of discussion. Since the concentrations of the pollutants are correlated, it is complex to distinguish their health effects and overestimation might occur (COMEAP, 2015a).

In 2013, the HRAPIE project of the WHO recommended a RR of 1.055 (95% CI = 1.031, 1.08) per 10 $\mu g/m^3$ increase of NO_2. However, an overestimation of 0-33% percent was predicted based on multipollutant analysis available at that moment. More recent analysis stated that the RR for all-cause mortality related to NO_2 is 1.02 (95% CI = 1.01, 1.03) per 10 $\mu g/m^3$ increment (Atkinson *et al.*, 2018). This corresponds to the RR of 1.02 (95% CI = 1.02, 1.02) found in the study of Fischer *et al.* (2015) for a two-pollutant model with PM_{10} adjustment. Besides, the COMEAP recommended a coefficient of 1.023 (95% CI = 1.008, 1.037) (COMEAP, 2018). If a RR of 1.02 is taken for HIA of all-cause mortality, no adjustment for other pollutants is necessary.

A RR of 1.062 (95% CI = 1.040, 1.083) per 10 $\mu g/m^3$ increase for the effect on all-cause mortality due to long-term $PM_{2.5}$ exposure is recommended by the HRAPIE project. Adjustment for NO_2 in two-pollutant models did not differ from single-pollutant models (Beelen *et al.*, 2014).

The evidence on the long-term effects of PM_{10} on all-cause mortality is less defined. A review of Hoek *et al.* (2013) showed a RR of 1.035 per 10 $\mu g/m^3$ (95% CI = 1.004, 1.066), but noted that this is based on little evidence. Therefore, this RR should only be used as sensitivity analysis when conducting HIA.

Janssen *et al.* (2011) found a pooled estimate RR of 1.06 (95% CI = 1.04, 1.09) per 1 $\mu g/m^3$ increase EC on all-cause mortality related to long-term exposure, where Hoek *et al.* (2013) found a pooled estimate RR of 1.061 (95% CI = 1.049, 1.073).

Table 1. Recommended Relative Risks for all (natural) cause mortality.

Pollutant	**RR (95% CI)**	**Source**
NO_2 (per 10 µg/m^3)	1.02 (1.01, 1.03)	Atkinson *et al.* (2018)
PM_{10} (per 10 µg/m^3)	1.035 (1.004, 1.066)	Hoek *et al.* (2013)
$PM_{2.5}$ (per 10 µg/m^3)	1.062 (1.040, 1.083)	HRAPIE (WHO, 2013b)
EC (per 1 µg/m^3)	1.061 (1.049, 1.073)	Hoek *et al.* (2013)

2.2.2 Evidence for morbidity

Much research has been conducted on the association between air pollution and morbidity health outcomes. In the context of the project of the current report, the evidence described in this subchapter is considered as the most eminent.

Most of the evidence for morbidity health indicators have been reviewed in the HRAPIE project for data available until 2013 (WHO, 2013b).

Furthermore, an association between long-term $PM_{2.5}$ exposure has been found with low birth weight (< 2500 g), lung cancer, and reduced lung function in school aged children (FEV1) with a RR of 1.19 (95% CI = 1.00, 1.42), a RR of 1.09 (95% CI = 1.04, 1.14), and percentage decrement 1.5% (95% CI = 0.3%, 3.2%) per 10 µg/m^3 respectively (Van der Zee *et al.*, 2016).

2.3 Uncertainties input data

The modelling of the level of exposure to air pollutants carries uncertainties. In order to calculate population-weighted concentrations, concentrations and population density data is needed. Most people do not spend 24 hours per day at home, which may lead to exposure misclassification. Though, in Europe, adults spend the majority of their time indoors at home (56-66%), which suggests that home address might be a reasonable proxy for individual exposure (Schweizer *et al.*, 2006). However, using home address as a proxy does not account for the difference in individual exposure due to the distance to busy streets or the extent to which houses are ventilated. Besides, it is hard to estimate the changes in air pollutant concentrations arising from air quality measures, especially on the local level. Emission estimates and modelling are not yet advanced enough to be of real help in this.

To use HIA tools, a baseline rate of incidences to the corresponding health indicator is used. The monitored data might deviate from the actual number of cases. Besides, often incidence rates of the entire country are used, and not only of the population that is being studied. Sometimes the data used is substantially outdated and might not be representative for the current situation. The same caveats apply to population characteristics data.

Researchers can interpret the weighting of studies on their qualitative strengths and weaknesses for doing meta-analysis on RRs differently. This also causes uncertainties of HIA.

When results of epidemiological studies are applied in order to calculate health effects in different populations, it is assumed that health risks occur systematically and not at random. Besides, it is assumed that risk factors (in this case air pollution) can be identified of being responsible to cause adverse health effects. Besides, CRFs often have less evidence for lower concentrations, because populated areas often show pollution to at least some extent. Because of this, CRFs are more reliable when applied to concentrations most studies are conducted with and less reliable for relatively low or high concentrations.

When interpreting HIA results, the counterfactual value should be noted. The counterfactual value chosen in the HIA does not increase the level of uncertainties by itself, but does influence the estimated health risks in an absolute manner. Note that when comparing different scenarios, results are not very sensitive for assumptions on counterfactual concentrations.

3. HIA results

3.1 Number of premature deaths or attributable cases of disease

With the input data mentioned in chapter 2, the attributable fraction to the total burden of disease due to risk factors can be calculated. This can be done for morbidity and mortality health indicators that have been associated with risk factors in epidemiological studies (see chapter 2.2). The methodology for doing calculations has been described by De Leeuw and Horálek (2016).

Because the RRs come from cohort studies, these results are only applicable to whole populations and not applicable individually. For both attributable deaths and cases of disease, it is not possible to identify which individual cases are caused by air pollution. RRs do not make a distinction between cases that would have occurred without exposure and cases in which the risk factor contributed to the development of the disease or death (Brunekreef, Hurley, & Miller, 2007, Knol *et al.*, 2009). An alternative approach is to calculate the years of life lost, which will be explained in chapter 3.3.

Besides, the attributable cases of deaths and disease of two moments in time cannot be compared if population characteristics are not static. For example, if the population ages, the number of attributable deaths and cases of disease might increase even though risk factors decrease.

3.2 Decline in life expectancy

If next to the age structure, the mortality rates of all (natural) cause or cause-specific deaths are known, life table calculations can be carried out to calculate the average statistical decline in life expectancy in the population. An advantage of calculating loss in life expectancy is that it gives a better description of the reality, since every person is affected by the risk factors to a greater or lesser extent. Every individual’s loss in life expectancy will vary around the average decline.

3.3 Years of Life Lost

The years of life lost (YLL) give an estimation of the years that in the whole population are lost due to the health risk factor. This can be calculated by multiplying the number of attributable deaths with the remaining life expectancy at the age of death. More information about the methodology can be found in the paper of De Leeuw and Horálek (2016).

When the YLL due to air pollution are calculated, this can be compared to the YLL due to other risk factors. Besides, the YLL are a part of the disability-adjusted life years (see chapter 3.5) and of the monetary valuation of health impacts (see chapter 3.6).

3.4 Years lost due to disability

The years lost due to disability (YLD) give an estimation of the years lost due to a part of the population being in the condition of being diseased due to the health risk factor. The total life years lost due to disability per case can be calculated by multiplying the disability weight factor with the average duration of the disease. The disability weight factor reflects the extent of the disability associated with living with the disease and varies between 0 and 1, with 0 meaning perfect health and 1 meaning death. For instance, having a chest cold for a week has a short duration and a low disability weight, whereas being wheelchair bound after an accident has a long duration and a high disability weight. The weighing of disabilities requires explicit choices that are inevitably subjective. There are several weighing schemes, for example see disability weight factors in Bachmann and Van der Kamp (2017), Heimtsa&Intarese (2011), and WHO (2017a).

As described for the YLL, the YLD due to air pollution can be compared to the YLD due to other risk factors and they form a part of DALYs and of the monetary valuation of health impacts.

3.5 Disability-adjusted life years

DALYs are the sum of the YLL and the YLD, giving a relevant measure of the burden of disease because it comprises both mortality and morbidity. As applies to the YLL and the YLD, an advantage of calculating DALYs is that it allows comparison of different morbidity health indicators and between other health risk factors such as noise pollution or smoking.

When adding YLL and/or YLD there may not be overlap in the health indicators used. An example of a morbidity health indictor that shows overlap with many other health indicators is restricted activity days (RADs) due to short-term $PM_{2.5}$ exposure. Overlapping indicators with RADs are for example asthma symptoms in asthmatic children, workdays lost, and hospitalizations. In addition, calculated YLL cannot always be added to each other, as explained in paragraph 2.2.1. Only one of the particulate matter indicators (PM_{10}, $PM_{2.5}$, or BC/EC) should be chosen and a RR with adjustment for the pollutants it is added to should be taken (e.g. for NO_2). More information about the use of DALYs can be found in the paper of Rushby & Hanson (2001).

3.6 Comparison of mortality health indicators

Different mortality health indicators can be meaningful depending on their application. Mortality effects can be expressed in premature deaths, average decline in life expectancy, and the YLL. When the indicator is used within scientific organizations, it is preferred to use an indicator that describes the situation the most accurately. However, when the indicator is used as a communicative tool, for instance to create awareness among the public, it is preferred to use an indicator that is most easily understood. The YLL describe the actual health impact of the risk factor on mortality in the most accurate way as opposed to quantifying the number of premature deaths and average decline in life expectancy. This is because they do not give any information about the risk to individuals. The disadvantage of using the YLL is that it does not have an appealing effect on policy makers or the public because it is hard to understand the large number. This makes the YLL a less attractive indicator to use as a communicative tool. The premature deaths and average in decline in life expectancy do give information about the risk for an average person, but as the sensitivity differs among people, such risks cannot be applied at an individual level. Even though it has to be interpreted with care, communicating the premature deaths does have a great impact on the public by creating awareness of the effects of air pollution on public health (A. Knol, personal communication, April 25, 2018). This can be helpful to push decision-making processes towards the implementation of air quality improvement measures.

3.7 Costs of health impacts

Assessing the costs of health impacts increases the awareness of the urge of focusing policy on decreasing air pollution compared to the health impact alone. For example, absenteeism has a lower impact on DALYs than on costs (Holland, 2014). To assess the total economic effect, several aspects of the health impact have to be taken into account, such as health care costs, the costs of absenteeism and/or restricted activity days and the costs of premature deaths or living with a disease (Amann, Holland, Maas, Saveyn, & Vandyck 2017). Costs that have been estimated in previous years should be corrected to the price level of the present year.

3.8 Uncertainties HIA results

HIA models always reflect a simplification of the real situation. As mentioned before, HIA is done by choosing a set of health indicators and is never the complete set of effects due to air pollution. Besides, different air pollutants have similar effects on various health endpoints that are difficult to distinguish due to their strong positive correlation.

The estimation of the costs of health impact is debatable, because it is often based on many assumptions (Holland, 2014). For example, when estimating the costs of bronchitis in children, it is assumed that children are affected only once per year. This is because epidemiological literature uses the definition whether children experienced bronchitis in the past year, not taking into account the

number of episodes. Besides, it is usually hard to estimate the costs of all the aspects of morbidity or mortality health indicators (Chanel *et al.*, 2014). For this reason, morbidity costs are often underestimated because intangible costs (such as the well-being of family and friends and loss of quality of life) and indirect costs (such as poorer customer fulfilment, poorer product or services quality, and the use of temporary staff) are often not taken into account in the assessment of the economic costs due to disease. Chanel *et al.* (2014) conducted a comprehensive assessment, taking all previous mentioned costs into consideration and found that only 0.15% of their calculated costs is accounted for in methods that only assess the direct costs (such as hospital stays, drugs, and costs of rehabilitation).

The results of HIA indicate that a reduction of health risks will occur in the same year as the reduction in air pollutant concentration. However, health benefits because of better air quality are not directly observable. Unfortunately, scientific evidence of the extent of this lag or latency is lacking for most health indicators.

When implying policy, HIA is often used in the decision-making process to calculate the change in health impact after different interventions. This prediction modelling increases the uncertainties of the results, because predictions about the future are never a completely correct reflection of how the actual situation is going to be.

4. HIA tools for air pollution

4.1 First selection HIA tools for air pollution

The aim of this project is to develop a package for municipalities of European cities to make HIA usable. Because developing a new tool is time and labor intensive, it is desirable to find an already existing tool that is usable within the context of this project. Based on suggestions from experts and our own research, various existing tools have been selected for further evaluation on their usability: GGD (Netherlands Public Health Services), AirQ+ (WHO), Aphekom, HEAT (WHO), SHERPA (JRC), GAINS (IIASA), IOMLIFET, EcoSense, TM5-FASST.

To achieve the best recommendations for HIA in European cities, non-structured interviews were held with experts (Table 2) on HIA. Annex 1 presents the main message of these interviews. Next to these interviews, direct personal communication took place with many of the experts during the research.

Table 2. Interviewed experts in air pollution-HIA in cities.

Name	**Institution(s)**
Bert Brunekreef	Utrecht University Institute for Risk Assessment Sciences (IRAS) World Health Organization (WHO)
Rob Maas	Netherlands National Institute for Public Health and the Environment (RIVM)
Floor Borlée	City of Utrecht, department for public health
Frank de Leeuw	Netherlands National Institute for Public Health and the Environment (RIVM), European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM)
Saskia van der Zee	Dutch public health services (GGD), department for environment and health, Co-developer of the GGD tool
Rik van de Weerdt	Dutch public health services (GGD), Co-developer of the GGD tool
Paul Fischer	Netherlands National Institute for Public Health and the Environment (RIVM), department for sustainability, environment and health, Co-developer of the GGD tool
Thomas Griebe	City of Duisburg
Anne Knol	Dutch environmental defense (Milieudefensie), campaign leader for sustainable mobility
Irene van Kamp	Netherlands National Institute for Public Health and the Environment (RIVM), department for sustainability, environment and health
Loes Geelen	Dutch public health services (GGD), PhD in air pollution-HIA

Based on these interviews, selection criteria were formulated. The first selection of tools was tested on the following criteria:

- Usefulness on city level
- Rich model output (i.e. the extensiveness of calculating mortality and morbidity health effects)
- The possibility to calculate health effects for different components of air pollution (e.g. PM_{10}, $PM_{2.5}$, EC/BC, NO_2)
- The possibility to adjust parameters (e.g. RRs, age structure, counterfactual levels, incidence rates)
- Up-to-date and scientific robust RRs
- General accessibility
- Modest data requirements, option to use default values

Table 3. Shown are the results of the first selection requirements for air pollution HIA tools.

Requirements Tool	City level	Rich model output	Different air pollutants	Adjustable parameters	Up-to-date RRs	General accessible	Modest data requirements
GGD	+	+	+	+	+	+	+
AirQ+	+	+	+	+	+	+	+
Aphekom	+	-	+/-	+	-	+	+
HEAT	+	-	-	+	+	+	-
SHERPA	+	-	-	-	+	+	+
GAINS	-	-	-	-	+	+/-	+
IOMLIFET	+	-	+	+	+	+	+
EcoSense	n/a	n/a	n/a	n/a	n/a	-	n/a
TM5-FASST	n/a	n/a	n/a	n/a	n/a	-	n/a

After testing the tools on the criteria, the GGD and AirQ+ tool met the requirements (Table 3). Therefore, these have been evaluated in depth.

4.2 In-depth evaluation AirQ+ and GGD tool

The AirQ+ tool is developed by the WHO and can be downloaded from the following website: http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/activities/airq-software-tool-for-health-risk-assessment-of-air-pollution. The tool is meant for any stakeholder that wants to carry out HIA and is developed in the form of software. To carry out an impact evaluation, concentration and population data have to be inserted. Also, an incidence rate should be inserted for the chosen health indicator. RRs and counterfactual levels are set on default values but are adjustable. This makes the tool usable in any population where relative risks have been derived from epidemiological studies. The default RRs make the tool usable for populations in Western Europe and North America, since most scientific evidence comes from studies in these regions. These default RRs have been reviewed in the HRAPIE project (WHO, 2013b). However, the two health indicators ‘Mortality due to ALRI for children (0-5 years) due to PM2.5’ and ‘Mortality, all (natural causes) due to BC’ have not been reviewed in the HRAPIE project and no reference of the default relative risks can be found in the tool. The default counterfactual values are the WHO AQG, but are adjustable. Many morbidity and mortality health indicators are included in the software but for every health indicator a separate analysis has to be carried out. This makes it labor intensive to conduct a complete HIA containing all the available health indicators. The AirQ+ tool also allows the user to do life table calculations to calculate the decline in life expectancy, on a condition that population and mortality hazard rates are known for age groups of at least five years.

The GGD tool is developed by the Dutch Public Health Services and can be downloaded from the following website: https://www.ggdghorkennisnet.nl/thema/gezondheid-en-milieu/publicaties/publicatie/17943-kwantificeren-van-de-gezondheidsschade-door-luchtverontreiniging-voor-ggd-en.
The aim of the tool is to give other health services in the Netherlands the opportunity to carry out HIA in their region. Because not all health service departments in the Netherlands have expertise in HIA, the tool was built so that only the pollutant concentrations and number of exposed people have to be inserted. Information such as age structure, incidences, and RRs are fixed numbers applicable to the Dutch population. These fixed numbers can be traced in the model, but cannot be changed. This makes the tool not applicable for other European countries. The strength of the tool is its pragmatic interface. The tool comes as an Excel spreadsheet in which only a few numbers have to be inserted and consequently the entire analysis automatically appears on the sheet. In this way, the user of the tool can see the effects of all included air pollutants and health indicators at a glance.

Detailed information on the AirQ+ tool and GGD tool are summarized in the factsheets in Annex 2.1 and Annex 2.2 respectively.

Because the AirQ+ tool does not allow the user to do many analyses at the same time and the GGD tool is only applicable to the Dutch population, it was chosen to combine the strengths of both tools by adapting the Excel spreadsheets of GGD tool to a tool for every European city. This process is described in chapter 5.

5. PAQ2018 tool

The PAQ2018 tool has been developed by the Urban Partnership for Air Quality, Action N°4 – Better Focus on the Protection and on the Improvement of Citizens' Health. As described in chapter 4, several tools have been evaluated on their strengths and weaknesses on their use by municipalities of European cities. The tool is an adaptation of the AirQ+ and GGD tool. The strengths of these tools have been combined. In this chapter, the development of the PAQ2018 tool will be described. The development year is implemented in its name, so that it is clear when it was last updated. If the tool will be updated in the future, the year will be updated as well.

The tool is in the form of an Excel spreadsheet and can be downloaded from: https://ec.europa.eu/futurium/en/air-quality. The package contains the tool, a step-by-step instruction, and the current paper for extensive background information.

5.1 Adaptations from AirQ+ and GGD to PAQ2018 tool

Age structure

The GGD tool contains the age structure of the Netherlands. The AirQ+ tool asks the user to insert the percentage of people the health indicator is applied to for every new impact analysis. The PAQ2018 tool contains the age structure of the European Union (Eurostat, 2015) as default values and is customizable. On the 'Age Structure' sheet in the tool the age structures of most European countries can be found. For more information, see chapter 2.1.1 of the current report.

Counterfactual values

The GGD tool does not have counterfactual values implemented because the GGD experts do not assume a concentration level below which no health risks occur. The AirQ+ counterfactual values are set on the WHO AQG maximum values and are adjustable. The PAQ2018 tool has default counterfactual values of 3.9 µg/m^3 for PM$_{10}$, 2.5 µg/m^3 for PM$_{2.5}$, 5 µg/m^3 for NO$_2$, and 0.3 µg/m^3 for EC based on expert recommendations (see chapter 2.1.3). These values are adjustable on the 'Input and Results' sheet in the tool below the cell mentioning 'Counterfactual concentration'. For more information on counterfactual values, see chapter 2.1.3 of the current report.

Incidence of health indicators

The GGD tool contains incidence data of health indicators of the Netherlands that are implemented in the model, and are thus not adjustable. To use the AirQ+ tool, incidence data has to be collected in order to conduct analysis, because no default values are present. The PAQ2018 tool requires the user to insert their own incidence/prevalence data before HIA results will appear. Instructions on how to find this data can be found in the instructions. In case no incidence data is available, default values standing next to the cells where the incidences have to be inserted can be used. For more information, see chapter 2.1.4 of the current report.

Calculate health loss or benefit of two scenarios

The GGD tool and AirQ+ tool allow the user to calculate the health impact of one scenario at a time. If the difference between two scenarios is to be calculated this has to be done manually. The PAQ2018 tool allows the user to input two different scenarios with different concentrations and the difference in health impact is automatically calculated on the 'Input and Results' sheet.

Decline in life expectancy

The GGD tool calculates mortality health impact as average decline in life expectancy. This is based on the age structure and mortality rates of the Netherlands. The calculations are done using the spreadsheets for life-table calculations developed by IOMLIFET (version 2013). To make the

PAQ2018 tool applicable to the European population, the age structure and mortality rates of the European population were inserted into the IOMLIFET spreadsheets instead of the Dutch data. The European population data was derived based on the methodology of De Leeuw and Horálek (2016). It was chosen to only calculate the European decline in life expectancy to the corresponding air pollutant concentration to keep the use of the PAQ2018 tool transparent for a large audience. If users wish to calculate the decline in life expectancy that is more accurate for their population of interest, the spreadsheets and background literature of IOMLIFET (Miller, 2013) can be consulted for doing calculations. More information about the decline in life expectancy can be found in chapter 3.2.

Extension of mortality health indicators

In the GGD tool, only decline in life expectancy was chosen as a health indicator for mortality (next to post-neonatal mortality). The AirQ+ tool only calculates the attributable deaths and YLL. For policymakers it is useful to have the opportunity to choose an appropriate outcome useful for their aim (Lhachimi *et al.*, 2010). Therefore, a rich model output is desirable and decline in life expectancy, attributable deaths and YLL have been implemented in the tool as mortality health indicators.

Premature deaths are calculated in the same manner as attributable cases of disease. How this is calculated can be found in chapter 3.1.

The YLL are calculated by multiplying the number of premature deaths with the average amount of years lost by a premature death in the EU-28, namely 10.6. This factor has been calculated based on the data on premature deaths and YLL given in EEA (2017). More information about the methodology can be found in chapter 3.3.

Different approach on double-counting PM and NO_2

The GGD tool calculates the decline in life expectancy for every pollutant in a one-pollutant model and PM_{10} and NO_2 together in a two-pollutant model. The one-pollutant model contains RRs of 1.035, 1.062, 1,055 per 10 µg/m^3 increase for PM_{10}, $PM_{2.5}$, and NO_2 respectively and a RR of 1,061 per 1 µg/m^3 increase of EC (Janssen *et al.*, 2011, Hoek *et al.*, 2013). The two-pollutant model contains RRs of 1.043 and 1.019 per 10 µg/m^3 increase of PM_{10} and NO_2 respectively (Fischer *et al.*, 2015).

The PAQ2018 tool does not contain one- or two-pollutant models because a lower RR for NO_2 is implemented allowing summation with the effects of PM. A RR of 1.02 was chosen based on the literature of Atkinson *et al.* (2018). More information can be found in chapter 2.2.1. The RRs for PM_{10}, $PM_{2.5}$, and EC remain the same (Table 5).

YLDs, YLL and DALYs

As mentioned in chapter 3, it is useful to calculate the YLD, YLL and DALYs. In the PAQ2018 tool, these indicators have been added to the analysis. The disability weights and durations of disease chosen can be found in table 4. Restricted Activity Days were excluded due to their overlap with other health indicators (e.g. hospital admissions, work days lost, etc.).

Table 4. Disability weights, durations, and costs used for the health indicators in the PAQ2018 tool.

Health indicator	Disability weight	Duration (years)	Source	Costs per unit (€) (e)
Annual number of days with bronchitis in children (age 6-12 years)	0.225	0.00274	(a)	49
Incidence chronic bronchitis in adults (age 18+ years)	0.099	10	(b)	62712
Incidence of asthma symptoms in asthmatic children (age 5-19years)	0.070	0.00274	(b)	49
Hospitalizations, cardiovascular diseases	0.588	0.038	(c)	2574

Hospitalizations, respiratory diseases	0.408	0.038	(c)	2574
Work days lost, working age population (age 20-65 years)	0.099	0.00274	(b)	152
Lung cancer (age 30+ years)	0.451	1	(a)	
Post-neonatal mortality (age 1-12 months)	1	80	(b)	
Premature deaths	1	10.6 (d)	(c)	67500

(a) WHO (2017a)
(b) Heimtsa & Interese (2011)
(c) Bachmann & van der Kamp (2017)
(d) See text chapter 5.1
(e) Holland (2014), corrected to price levels of 2015. Amounts are based on the lower limits.

Costs of health impact

When implementing policy, the costs of health risks are an effective criterion in the decision-making process. Therefore, it was chosen to add the costs of health damage in euros to the analysis in the tool. Monetary values used can be found in table 4. Restricted Activity Days were excluded due to their overlap with other health indicators (e.g. hospital admissions, work days lost, etc.). Lung cancer, low birth weight, decreased lung function, and post-neonatal mortality were also excluded because no monetary value has been estimated (Holland, 2014). The health damage in € in the tool is based on the sum of costs due to the morbidity health outcomes with an indicated cost per unit and the YLL due to $PM_{2.5}$ and NO_2.

A way to deal with uncertainties of HIA is to take into account the 95% confidence intervals (CIs). Therefore, these intervals are implemented in the PAQ2018 tool (Table 5). More information about how to tackle uncertainties in HIA can be found in chapter 2.3.

Table 5. Risk estimates and 95% Confidence Intervals used in the PAQ2018 tool. Risk estimates are given in Relative Risk for all health indicators except for decreased lung function (FEV1) (age 6-12 years), which is given in percentage decline.

Risk Factor	Health indicator	Risk Estimate (95% CI)	Source
PM_{10}	Annual number of days with bronchitis in children (age 6-12 years)	1.08 (0.98 - 1.19)	WHO (2013b)
PM_{10}	Incidence chronic bronchitis in adults (age 18+ years)	1.117 (1.040 - 1.189)	WHO (2013b)
PM_{10}	Incidence of asthma symptoms in asthmatic children (age 5-19 years)	1.028 (1.006 - 1.051)	WHO (2013b)
$PM_{2.5}$	Hospitalizations, cardiovascular diseases	1.0091 (1.0017 - 1.0166)	WHO (2013b)
$PM_{2.5}$	Hospitalizations, respiratory diseases	1.0190 (0.9982 - 1.0402)	WHO (2013b)
$PM_{2.5}$	Restricted activity days (RADs) (including sick-leave, hospital emergency admission, symptom days)	1.047 (1.042 - 1.053)	WHO (2013b)
$PM_{2.5}$	Work days lost, working age population (age 20-65 years)	1.046 (1.039 - 1.053)	WHO (2013b)
$PM_{2.5}$	Lung cancer (age 30+ years)	1.09 (1.04 - 1.14)	Van der Zee *et al.* (2016)
$PM_{2.5}$	Low birth weight (< 2500 g at term)	1.19 (1.00 - 1.42)	Van der Zee *et al.* (2016)
$PM_{2.5}$	Decreased lung function (FEV1) (age 6-12 years)	1.5% (-0.3% - 3.2%)	Van der Zee *et al.* (2016)
PM_{10}	Post-neonatal mortality (age 1-12 months)	1.04 (1.02 - 1.07)	WHO (2013b)
PM_{10}	All-cause mortality	1.035 (1.004 - 1.066)	Hoek *et al.* (2013)
$PM_{2.5}$	All-cause mortality	1.062 (1.041 - 1.084)	Hoek *et al.* (2013)

NO_2	All-cause mortality	1.02 (1.01 - 1.03)	Atkinson *et al.* (2018)
EC	All-cause mortality	1.061 (1.049 - 1.073)	Hoek *et al.* (2013)

5.2 Pilot study PAQ2018 tool

The PAQ2018 tool was recommended for cities to use in the context of the PAQ. To test the tool it was send to partner cities that were asked to conduct a HIA and fill in a feedback form for further improvement. The cities that conducted the pilot were Helsinki, Duisburg, Utrecht, Karlsruhe and Slavonski Brod. The main improvements made based on the feedback are:

- No default analysis values of Utrecht, because it is not clear which values are old values and which values have been newly calculated.
- The counterfactual values have been made adjustable.
- The RR for NO_2 on all-cause mortality has been updated to the most recent findings.
- 95% confidence intervals have been implemented in the results.

5.3 Example calculation with the PAQ2018 tool

With this tool, the health benefit/loss of a change in air quality can be assessed. Nonetheless, it is also possible to calculate the health impact of one or several pollutants at one moment in time.

What is the health benefit/loss of a 50% car reduction in Utrecht? In this analysis, counterfactual values have been set on 3.9 µg/m^3 for PM_{10}, 2.5 µg/m^3 for $PM_{2.5}$, 5 µg/m^3 for NO_2, and 0.3 µg/m^3 for EC. Incidence data of Utrecht has been used.

The following concentrations have inserted:

Pollutant	**Base case (Utrecht 2016)**	**Scenario Utrecht with 50% car reduction**	**Calculated concentration difference**
PM_{10} (in µg/m^3)	20.41	19.94	0.47
$PM_{2.5}$ (in µg/m^3)	12.69	12.46	0.23
NO_2 (in µg/m^3)	28.95	25.87	3.08
EC (in µg/m^3)	1.22	1.12	0.10

Scenario results:

Health indicator	**Health benefit in cases (Mean (95% CI))**	**Health benefit in share of disease burden in % (Mean (95% CI))**
Annual number of days with bronchitis in children (age 6-12 years) (PM_{10})	95 (-30 - 185)	0.3 (-0.1 - 0.6)
Incidence chronic bronchitis in adults (age 18+ years) (PM_{10})	3 (1 - 4)	0.4 (0.2 - 0.6)
Incidence of asthma symptoms in asthmatic children (age 5-19 years) (PM_{10})	225 (51 - 392)	0.1 (0.0 - 0.2)
Hospitalizations, cardiovascular diseases ($PM_{2.5}$)	1 (0 - 2)	0.0 (0.0 - 0.0)
Hospitalizations, respiratory diseases ($PM_{2.5}$)	1 (0 - 2)	0.0 (0.0 - 0.1)
Restricted activity days (RADs) (including sick-leave, hospital emergency admission, symptom days) ($PM_{2.5}$)	6576 (5919 - 7351)	0.1 (0.1 - 0.1)
Work days lost, working age population (age 20-65 years) ($PM_{2.5}$)	2061 (1765 - 2351)	0.1 (0.1 - 0.1)
Lung cancer (age 30+ years) ($PM_{2.5}$)	0 (0 - 0)	0.2 (0.1 - 0.3)
Low birth weight (< 2500 g at term) ($PM_{2.5}$)	1 (0 - 1)	0.3 (0.0 - 0.6)

YLD benefit	4 (2 - 6)

Reduction decline FEV1	0.0% (0.0% - -0.1%)

Health indicator	Health benefit premature deaths (Mean (95% CI))	Health benefit in share of disease burden in % (Mean (95% CI))	Reduction decline in life expectancy in days (Mean (95% CI))	Gained YLL (Mean (95% CI))
Post-neonatal mortality (age 1-12 months) (PM$_{10}$)	0 (0 - 0)	0,2 (0,1 - 0,3)	-	0 (0 - 1)
Mortality due to PM$_{10}$	4 (1 - 8)	0,2 (0,0 - 0,3)	6 (1 - 10)	46 (6 - 81)
Mortality due to PM$_{2.5}$	4 (2 - 5)	0,1 (0,1 - 0,2)	5 (3 - 6)	39 (26 - 51)
Mortality due to NO$_2$	16 (8 - 24)	0,6 (0,3 - 0,9)	21 (11 - 32)	174 (89 - 254)
Mortality due to EC	16 (13 - 19)	0,6 (0,5 – 0,7)	21 (17 - 25)	167 (137 - 197)

Gained DALYs (Total YLD + YLL due to PM$_{2.5}$ & NO$_2$)	216 (117 - 310)
Reduced health damage in €	14,874,516 (8,154,587 – 21,236,649)

6. Discussion

6.1 PAQ2018 tool and its use

To underpin the role of HIA in air quality policy in European cities, a package with the PAQ2018 tool, step-by-step instructions, and the present background document has been developed. The PAQ2018 tool is an adaptation of the GGD tool and the AirQ+ tool. The strengths of these tools have been combined in order to function as an easy accessible method for the implementation of HIA by European cities throughout the regulatory process. This process has been described in chapter 5 of the present paper.

The implementation of HIA can support air policy in different ways. Firstly, acceptance of air measures that can be experienced as ‘inconvenient’ can be supported. HIA results can help policy makers and other stakeholders to communicate the urge of implementing measures that improve air quality. When the health effects of these measures are being communicated, it is clearer to the public what it means for public health. Secondly, HIA can help to create awareness amongst the public. Even though exposure to air pollution has been extensively associated with adverse health effects, it is difficult to create public awareness. When these health effects are being communicated, it is more likely that public awareness will rise. Another way to utilize HIA is by modelling alternative policy options. For example, by giving insights in which option will produce the greatest progress for both transport and health when making plans for road construction (Dhondt *et al.*, 2013).

In the context of the Aphekom project, it has been evaluated in which manner twenty-seven scientists, who had a full understanding of HIAs, think about the application of HIA results. Certain respondents believe results should only be used as a communicative tool in order to raise awareness and inform policy makers and the public, but that it should not be decisive due to the extensiveness of uncertainties. Others think that policy implementation can be decided based on the results (Aphekom, 2011). The PAQ2018 tool is meant for use by European cities, which are encouraged to thoroughly consider the pitfalls and strengths of HIA results, which their decision on practical implementation of the results should be based upon.

6.2 HIA pitfalls

One of the pitfalls of HIA is that it is based on many assumptions. Examples are assumptions concerning the RRs, not accounting for a lag of the health effects, not accounting for an increased susceptibility of sensitive populations, the applicability of the model in the scenario being studied, a lack of the explanation of economic valuations, etc. (Aphekom, 2011). These assumptions, next to other aspects of the model (see chapter 2.3) lead to uncertainties in the results of the analysis. These uncertainties have to be taken into consideration and results of HIA should be interpreted with care (see chapter 3). A possible solution for tackling this problem is to also communicate a range in which the actual result is most likely located, taking into account every uncertainty. Many epidemiological studies therefore give a 95% confidence interval (CI), which gives information about how precisely the relative risk is estimated. The broader the interval, the less well the mean is determined. Assuming the relative risk estimate itself is unbiased, it is 95% certain that the actual number lays in the 95% CI’s. Because the 95% CIs are known for most RRs, these have been implemented in the PAQ2018 tool. An uncertainty range that covers more uncertainty factors (such as the uncertainty in future predictions) is the prediction interval (Atkinson *et al.*, 2018), which gives information about the distribution of the data, including uncertainties plus data scatter. In the case of HIA, communicating the prediction interval would cover all the assumption established regarding the analysis. According to Atkinson (2018), meta-analyses should have the prediction interval added next to the confidence interval. Despite uncertainties, HIA results can operate as a useful and valid measure. The challenge of developing HIA tools lays in the thoroughness of the analysis and the usefulness for stakeholders who may not have expertise in the field of air pollution HIA. This involves adequate communication about the uncertainties of the results, and how to interpret and/or use them.

Another pitfall is that HIA can be conducted with very few data available that may deviate from the data of the population being studied, leading to greater uncertainties. Data that describes the population being studied the most accurate, will also result in the most accurate estimation of the health impact of air pollution (see chapter 2). Governing authorities should be encouraged to set up systems or databases with accurate monitoring of population data, such as age structure, all (natural) cause deaths, cause-specific deaths, and incidence rates of diseases.

When conducting HIA, this is often done for only a specifically chosen set of health indicators. This is due to different reasons, for example the non-sufficient or lack of evidence of the association between air pollution and certain health indicators. It is nearly impossible to calculate the complete impact of air pollution on morbidity, because of its very small contribution to the development of some diseases. Air pollution and diseases might not yet have been associated in epidemiological studies. HIA tools should be updated with future epidemiological evidence on the association between air pollution and health indicators. For this reason, the PAQ2018 tool carries the year it has last been updated in its name. This gives the user a quick insight of the recentness of the RRs implemented in the tool. When the tool is updated, its name should be updated as well. Another reason the HIA results are only a set of health indicators is to remain the results of the tool or analysis clear and comprehensive. Because the results are often used as an instrument to facilitate communication between stakeholders, HIA tools are often developed with the thought of providing a simple and clear message. However, because of above mentioned pitfalls of HIA, the results should be interpreted with care. The challenge lays in the completeness of the results and the pragmatic usability of the tool. During the development of the PAQ2018 tool this has been taken into consideration.

As mentioned before, HIA tools can operate to choose the best intervention option on several aspects. A pitfall of this method is that the level of exposure before and after intervention is often averaged over the total population that is being studied. Due to this averaging, it is not visible what the health benefit or loss is for individuals. When implying policy, it is desirable to improve the overall air quality, but not by having a great improvement for some individuals and a deterioration for others. As a solution, it should be looked into that the air quality does not decline extensively for some individuals.

6.3 Role of cities in air quality policy

A questionnaire conducted by the Aphekom Group, filled in by 321 stakeholders, revealed that stakeholders wish for more policy recommendations (Aphekom, 2011). HIA tools work as great communicative instruments, especially with the thought of facilitating a shift towards policy with citizens' health as a central theme. To achieve this shift, cities should be informed about what can be done to have an impact on improving air quality and citizens' health. The first step is to map sources of air pollution. Questions such as 'where do pollutants come from?' and 'which sectors provide the largest contribution to air pollution?' should be assessed. Several tools, such as SHERPA and GAINS can be informed. The FAIRMODE provides information on how to model air quality data.

When targeting $PM_{2.5}$, the Urban $PM_{2.5}$ atlas (SHERPA, 2017) can be informed for information about the spatial and sectoral allocation of $PM_{2.5}$ emission. This atlas gives the information that cities in Italy have a relatively high contribution to $PM_{2.5}$ from national residential sources. Based on this information, policy can be targeted on this sector, by for example the regulation of wood burning for residential heating and cooking. The atlas also gives insight on the spatial level emission of $PM_{2.5}$ (city, region, national, transboundary). This sometimes gives the insight that for some sectoral sources, cities have a relatively low contribution to the total emission and improvement should be realized on national and/or international levels. For example, in some Dutch cities (e.g. Eindhoven and Utrecht) the agricultural sector contributes to a relatively great extent but is hard to target by a city and is more easily influenced from national governing authorities. This highlights the urge of collaboration on all government levels, from city to national and even continental.

The Joaquin project has evaluated measures which are currently available to policy makers. For more information visit their website: http://www.joaquin.eu/. In addition, the document 'code of good practices' of the PAQ can be informed for effective air quality measures and what can be done to improve air quality legislation.

From a health perspective, one of the most effective measures is the promotion of active travel (walking and cycling) in cities. Not only does this reduce road-traffic related emission, which is one of the main sources of air pollution in urban areas, it also improves citizens' health because of physical activity. De Hartog *et al.* (2010) showed that the beneficial effects of cycling (3 to 14 months gained) outweigh the increased risk on mortality (0.8 to 40 days lost). If data about active transport inside the urban environment is present, the HEAT (Health economic assessment tool for walking and for cycling) tool can be used. This tool allows the user to calculate the mortality risks (in number of premature deaths) and the economic value of impacts for mortality related to (interventions concerning) active transport.

Accountability studies, defined by the Health Effects Institute (HEI Communication 11, 2003) operate as a framework to assess the effectiveness of air quality policy. Different methods have been used to assess relationships between regulations and the improvement of air quality and public health.

When emissions are located or the effects on pollutant concentrations have been modelled, the related health effects can be calculated with the PAQ2018 tool in order to create awareness amongst policy makers and the public. By doing so the urge of considering health impact when implementing policy will become more eminent. Besides, the economic damage due to air pollution will facilitate this shift. This will eventually lead to a reduction of the contribution to the burden of disease due to air pollution.

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Annex 1. Main message interviews with experts

Saskia van der Zee (23-04-2018)
Function: Dutch public health services (GGD, department for environment and health), co-developer of the GGD tool.

Q: In the GGD tool, absenteeism is covered in the indicator ‘restricted activity days’ and ‘work days lost’. Do these indicators overlap each other?
A: ‘Work days lost’ only covers the working population, ‘restricted activity days’ includes people of every age. Absenteeism is indeed covered by both indicators. Therefore, YLD of the indicators cannot be added to each other.

Q: Is there a counterfactual value implemented in the GGD tool?
A: No, there is no reason to assume that under certain levels of air pollution no health effects occur. Therefore, there are no counterfactual values implemented in the GGD tool.

Q: Which interventions have been the most effective?
A: Sharpening the European emission standards, emission restrictions for the industry, closing down coal-fired power stations, low emission zones. In the future, there should be focused on shipping, wood burning, and mobile equipment.

Q: Is it possible to compare air quality measures with other measures that improve public health (such as the effect of greenness, physical activity and diet)?
A: De Hartog et al. (2010) concluded that the health benefit won by biking in polluted areas is significantly more than the health damage lost by breathing the polluted air: 3-14 months benefit against 0.8-40 days lost due to air pollution and 5-9 days lost due to traffic accidents.

Anne Knol (25-04-2018)
Function: Dutch environmental defense (Milieudefensie), campaign leader for sustainable mobility.

Q: In your article ‘Interpretation of premature deaths due to air pollution (2009, only available in Dutch), it is described that (reduced) Years of Life Lost is more meaningful to calculate than the premature deaths. Could you explain this?
A: It is not possible to distinguish people who die due to air pollution and people who do not. In reality, the entire population becomes less healthy, some individuals more than others. It is not possible to indicate which individuals have died due to air pollution, which a number of attributable deaths might indicate if interpreted wrongly. However, in my function at the Dutch environmental defense I have a different opinion about the use of these numbers, because it does have an impact on the public. The average years of life lost (approximately 13 months) does unfortunately not have a great impact on the public. It does not include the years lived with disease.

Paul Fischer (30-04-2018)
Function: Netherlands National Institute for Public Health and the Environment (RIVM), department for sustainability, environment and health, co-developer of the GGD tool.

NO2 and soot have the greatest local contribution. Variations in PM10 and PM2.5 are not as substantial within the city and have a greater contribution from sources outside cities.

Irene van Kamp (01-05-2018)
Function: Netherlands National Institute for Public Health and the Environment (RIVM), department for sustainability, environment and health. Conducts Health Impact Assessment for noise pollution.

The reduction of noise does not only lead to beneficial health effects, but also invites citizens to spend more time outdoors (e.g. in parks and active transport). This also has an effect on other environmental factors such as air pollution.

Loes Geelen (30-05-2018)
Function: Dutch public health services (GGD), PhD in HIA of air pollution in 2013.

The most appropriate health indicator to use depends on the question that is being answered. For example premature deaths of the years of life lost. Using both is also possible, because both are informative. Presenting more indicators offers a more realistic picture of the actual situation and shows several effects.

Annex 2.1 Factsheet AirQ+ tool

Introduction

The AirQ+ tool is developed by the WHO and can be downloaded from the following website: http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/activities/airq-software-tool-for-health-risk-assessment-of-air-pollution. The tool is meant for any stakeholder that wants to carry out HIA and is developed in the form of software. To carry out an impact evaluation, concentration and population data have to be inserted. Consequently, an incidence rate should be inserted for the chosen health indicator. Relative risks and counterfactual levels are set on default values but are adjustable. This makes the tool usable in any population where relative risks have been derived from epidemiological studies. The default relative risks make the tool usable for populations in Western Europe and North America, since most scientific evidence comes from studies in these regions. These default relative risks have been reviewed in the HRAPIE project (WHO, 2013b). The counterfactual default values are the WHO AQG, but are adjustable. Many morbidity and mortality health indicators are included in the software but for every health indicator a separate analysis has to be carried out. This makes it labor intensive to conduct a complete HIA containing all the available health indicators. The AirQ+ tool also allows the user to do life table calculations to calculate the decline in life expectancy, if population and mortality hazard rates are known for age groups of five years.

Characteristics

- Possibility to calculate the health effects of ambient air pollution (PM_{10}, $PM_{2.5}$, NO_2, BC, O_3) and household air pollution (solid fuel use)
- Adjustable counterfactual values (default on WHO AQG levels)
- Adjustable relative risks, making the tool usable for every population where relative risks have been derived from epidemiological studies
- The default relative risks make the tool usable for Western Europe and North America
- Every health indicator has to be analyzed in a separate analysis
- Possibility to conduct life table calculations with changing concentrations and birth rates
- No YLD and DALY calculations (see chapter 3)

Data input

Minimally required	**Desirably required**
• Total number of citizens in region • Concentration data of at least one of the pollutants • Baseline incidence/prevalence rates of the population	• For life table evaluation: age structure and mortality rates of the region • Concentration data of all the pollutants

Health output of ambient air pollution

Long term PM_{10}
- Years of life lost & expected life remaining
- Incidence of chronic bronchitis in adults
- Post-neonatal infant mortality, all cause
- Prevalence of bronchitis in children (6-12 years)

Long term $PM_{2.5}$
- Years of life lost & expected life remaining
- Mortality, all (natural) causes (adults age 30+ years)
- Mortality due to ALRI for children (0-5 years)*
- Mortality due to COPD for adults (30+ years)

- Mortality due to LC for adults (30+ years)
- Mortality due to IHD for adults (25+ years)
- Mortality due to Stroke for adults (25+ years)

Long term NO_2
- Years of life lost & expected life remaining
- Mortality, all (natural) causes
- Prevalence of bronchitic symptoms in asthmatic children

Long term BC
- Years of life lost & expected life remaining
- Mortality, all (natural) causes*

Long term O_3
- Years of life lost & expected life remaining
- Mortality, respiratory diseases

Short term PM_{10}
- Incidence of asthma symptoms in asthmatic children (5-19 years)

Short term $PM_{2.5}$
- Hospital admissions, respiratory disease
- Hospital admissions: CVD (including stroke)
- Mortality, all (natural) causes (adults age 30+ years)
- Restricted activity days (RADs) all ages
- Work days lost, working age population only (20-65 years)

Short term NO_2
- Hospital admissions, respiratory diseases (24-hour mean)
- Hospital admissions, respiratory diseases (max 1-hour mean)
- Mortality, all (natural) causes

Short term O_3
- Hospital admissions, CVDs (excluding stroke)
- Hospital admissions, respiratory disease
- Minor restricted activity days (MRADs)
- Mortality, CVDs
- Mortality, all (natural) causes
- Mortality, respiratory diseases

* The two health indictors ‘Mortality due to ALRI for children (0-5 years) due to PM2.5’ and ‘Mortality, all (natural causes) due to BC’ have not been reviewed in the HRAPIE project (WHO, 2013b). No reference of the default relative risks can be found in the tool.

What type of question can be answered with this tool?

The AirQ+ tool is most helpful if only one if the health indicators has to be calculated instead of a set of health indicators, because for every health indicator a separate analysis has to be conducted.

Example question

How many cases of premature deaths are attributable to an annual mean concentration of 15 µg/m^3 $PM_{2.5}$ on mortality (30+ years) on a population of 350,000 people, where 65% of the population is 30+ years old, and the baseline mortality incidence rate is 820 per 100,000 per year? For this analysis, a counterfactual value of 2.5 µg/m^3 was chosen.

The following results become visible:

	Central	**Lower**	**Upper**
Estimated Attributable Proportion	7.24%	4.78%	9.49%
Estimated number of Attributable Cases	135	89	177
Estimated number of Attributable Cases per 100,000 Population at Risk	59.40	39.23	77.79

From this figure, it can be derived that the previous described situation leads to an estimated number of 135 premature deaths in the population. This is an estimated attribution of 7.24% to the burden of disease. The column ‘central’ are the results based on the relative risk and the lower and upper are the results of the 95% confidence intervals.

Annex 2.2 Factsheet GGD tool

Introduction

The GGD tool is developed by the Dutch Public Health Services (GGD) Amsterdam and can be downloaded from the following website: https://www.ggdghorkennisnet.nl/thema/gezondheid-en-milieu/publicaties/publicatie/17943-kwantificeren-van-de-gezondheidsschade-door-luchtverontreiniging-voor-ggd-en. The aim of the tool is to make HIA comprehensible for other GGD departments in the Netherlands, because not all GGD departments have expertise in HIA. Therefore, the tool was built so that only the pollutant concentrations and number of exposed people have to be inserted. Information such as age structure, baseline incidence/prevalence rates, and relative risks are fixed numbers that are applicable to the Dutch population. These fixed numbers can be traced in the model, but cannot be changed. This makes the tool not applicable for other European countries. The strength of the tool is its pragmatic interface. The tool comes as an Excel spreadsheet in which only a few numbers have to be inserted and consequently the entire analysis automatically appears. In this way, the user of the tool can see the effect of all health indicators at a glance.

Characteristics

- Only applicable to the Dutch population (age structure, relative risks, and incidence/prevalence numbers are fixed in the model)
- Possibility to calculate morbidity health effects of PM_{10} and $PM_{2.5}$
- Possibility to calculate mortality health effects of PM_{10}, $PM_{2.5}$, NO_2 and EC (in decline of life expectancy) for both a one-pollutant and a two-pollutant model for PM_{10} and NO_2.
- No counterfactual values
- Very few data needed (only number of people and pollutant concentrations)
- Every health indicator will be calculated within one analysis
- No YLL and DALY calculations (see chapter 3)

Data input

Minimally required	**Desirably required**
• Total number of citizens in region • Concentration data of at least one of the pollutants	• Concentration data of all the pollutants

Health output of ambient air pollution

Morbidity health effects due to PM_{10}
- Annual number of days with bronchitis in children (age 6-12 years)
- Incidence chronic bronchitis in adults (age 18+ years)
- Incidence of asthma symptoms in asthmatic children (age 5-19 years)

Morbidity health effects due to $PM_{2.5}$
- Hospitalizations, cardiovascular diseases
- Hospitalizations, respiratory diseases
- Restricted activity days (RADs) (including sick-leave, hospital admission, symptom days)
- Work days lost, working age population (age 20-65 years)
- Lung cancer (age 30+ years)
- Low birth weight (< 2500 g at term)

Mortality health effects due to PM_{10}
- Post-neonatal mortality (age 1-12 months)
- Decline in life expectancy

Mortality in decline in life expectancy (age 30+ years) in days, for:

- Two-pollutant model: PM_{10} and NO_2 together
- One-pollutant model: PM_{10}, $PM_{2.5}$, NO_2, EC separately

Most of the health indicator relative risks have been recommended by the HRAPIE project (WHO, 2013b) except for 'lung cancer (age 30+ years)' (Van der Zee *et al.*, 2016), 'low birth weight (< 2500 g at term)' (Van der Zee *et al.*, 2016), 'decline in life expectancy due to PM_{10} and NO_2 (two-pollutant model)' (Fischer *et al.*, 2015), and mortality (all natural causes) due to EC (Janssen *et al.*, 2011).

What type of question can be answered with this tool?

With this tool, the health risks due to air pollution of populations in the Netherlands can be calculated. This can be done to analyze the health risks for one of the health indicators or for a complete set of health indicators for the different air pollutants at once.

Example question

What are the health risks of an annual mean concentration of 15 $\mu g/m^3$ $PM_{2.5}$ in a Dutch population of 350,000 people? For this analysis, no counterfactual value was chosen.

Results:

Health indicator	**Attributable cases**	**Attribution in disease burden**
Hospitalizations, cardiovascular disease	54	1%
Hospitalizations, respiratory disease	47	3%
Restricted Activity Days	442716	7%
Work days lost (20-65 years)	96820	7%
Lung Cancer (30+ years)	29	12%
Low Birth Weight (<2500g at term)	53	23%

FEV1 decline in children (6-12 years) in percentage	2.3%

Decline in life expectancy in days (30+ years) due to $PM_{2.5}$	300

Annex 2.3 Factsheet PAQ2018 tool

Introduction

The PAQ2018 tool is developed by the Urban Partnership for Air Quality, Action N°4 – Better Focus on the Protection and on the Improvement of Citizens' Health. For more information about the partnership visit https://ec.europa.eu/futurium/en/air-quality.

The tool is an adaptation of the AirQ+ and GGD tool. The strengths of these tools have been combined in order to make HIA feasible for municipalities of European cities in particular. See chapter 5 for information about the differences with the AirQ+ and GGD tool. The strengths of this tool are the pragmatic usability, its rich model output and its capability of conducting many analyses at once after which all the results become visible at a glance. Compared to the AirQ+ and GGD tool, the output has been extended with DALYs and the health damage in euros. Besides, with the PAQ2018 tool it is possible to calculate the health benefit or loss of two different pollution scenarios.

Characteristics

- Applicable to populations in Western Europe and North America
- Possibility to calculate morbidity health effects of PM_{10} and $PM_{2.5}$
- Possibility to calculate mortality health effects of PM_{10}, $PM_{2.5}$, NO_2 and EC (in decline in life expectancy, YLL, and premature deaths)
- Adjustable age structure
- Adjustable counterfactual values (substantiation default values see chapter 2.1.3)
- Adjustable baseline incidence rates
- Possibility to use default values of Europe
- Every health indicator will be calculated within one analysis
- Rich model output: morbidity (also YLD), mortality (in decline in life expectancy, YLL and premature deaths), DALYs, health damage in euros

Data input

Minimally required	**Desirably required**
• Total number of citizens in region • Concentration data of at least one of the pollutants	• Concentration data of all the pollutants • Baseline incidence rates of health indicators in the population

Health output of ambient air pollution

Morbidity health effects due to PM_{10}
- Annual number of days with bronchitis in children (age 6-12 years)
- Incidence chronic bronchitis in adults (age 18+ years)
- Incidence of asthma symptoms in asthmatic children (age 5-19 years)

Morbidity health effects due to $PM_{2.5}$
- Hospitalizations, cardiovascular diseases
- Hospitalizations, respiratory diseases
- Restricted activity days (RADs) (including sick-leave, hospital admission, symptom days)
- Work days lost, working age population (age 20-65 years)
- Lung cancer (age 30+ years)
- Low birth weight (< 2500 g at term)
- Decreased lung function (FEV1) (age 6-12 years) in percentage

Mortality health effects due to PM_{10}, $PM_{2.5}$, NO_2 and EC

- Post-neonatal mortality (age 1-12 months) (due to PM_{10})
- Premature deaths (for all pollutants)
- Decline in life expectancy (for all pollutants)
- Years of life lost (for all pollutants)

What type of question can be answered with this tool?

With this tool, the health benefit/loss of a change in air quality can be assessed. Nonetheless, it is also possible to calculate the health impact of one or several pollutants at one moment in time.

Example question 1

What is the health benefit/loss of a 50% car reduction in Utrecht? In this analysis, counterfactual values have been set on 3.9 µg/m^3 for PM_{10}, 2.5 µg/m^3 for $PM_{2.5}$, 5 µg/m^3 for NO_2, and 0.3 µg/m^3 for EC. Incidence data of Utrecht has been used.

The following concentrations have inserted:

Pollutant	Base case (Utrecht 2016)	Scenario Utrecht with 50% car reduction	Calculated concentration difference
PM_{10} (in µg/m^3)	20.41	19.94	0.47
$PM_{2.5}$ (in µg/m^3)	12.69	12.46	0.23
NO_2 (in µg/m^3)	28.95	25.87	3.08
EC (in µg/m^3)	1.22	1.12	0.10

Scenario results:

Health indicator	Health benefit in cases (Mean (95% CI))	Health benefit in share of disease burden in % (Mean (95% CI))
Annual number of days with bronchitis in children (age 6-12 years) (PM_{10})	95 (-30 - 185)	0.3 (-0.1 - 0.6)
Incidence chronic bronchitis in adults (age 18+ years) (PM_{10})	3 (1 - 4)	0.4 (0.2 - 0.6)
Incidence of asthma symptoms in asthmatic children (age 5-19 years) (PM_{10})	225 (51 - 392)	0.1 (0.0 - 0.2)
Hospitalizations, cardiovascular diseases ($PM_{2.5}$)	1 (0 - 2)	0.0 (0.0 - 0.0)
Hospitalizations, respiratory diseases ($PM_{2.5}$)	1 (0 - 2)	0.0 (0.0 - 0.1)
Restricted activity days (RADs) (including sick-leave, hospital emergency admission, symptom days) ($PM_{2.5}$)	6576 (5919 - 7351)	0.1 (0.1 - 0.1)
Work days lost, working age population (age 20-65 years) ($PM_{2.5}$)	2061 (1765 - 2351)	0.1 (0.1 - 0.1)
Lung cancer (age 30+ years) ($PM_{2.5}$)	0 (0 - 0)	0.2 (0.1 - 0.3)
Low birth weight (< 2500 g at term) ($PM_{2.5}$)	1 (0 - 1)	0.3 (0.0 - 0.6)

YLD benefit	4 (2 - 6)
Reduction decline FEV1	0.0% (0.0% - -0.1%)

Health indicator	Health benefit premature deaths (Mean (95% CI))	Health benefit in share of disease burden in % (Mean (95% CI))	Reduction decline in life expectancy in days (Mean (95% CI))	Gained YLL (Mean (95% CI))
Post-neonatal mortality	0 (0 - 0)	0,2 (0,1 - 0,3)	-	0 (0 - 1)

(age 1-12 months) (PM_{10})				
Mortality due to PM_{10}	4 (1 - 8)	0,2 (0,0 - 0,3)	6 (1 - 10)	46 (6 - 81)
Mortality due to $PM_{2.5}$	4 (2 - 5)	0,1 (0,1 - 0,2)	5 (3 - 6)	39 (26 - 51)
Mortality due to NO_2	16 (8 - 24)	0,6 (0,3 - 0,9)	21 (11 - 32)	174 (89 - 254)
Mortality due to EC	16 (13 - 19)	0,6 (0,5 – 0,7)	21 (17 - 25)	167 (137 - 197)

Gained DALYs (Total YLD + YLL due to $PM_{2.5}$ & NO_2)	216 (117 - 310)
Reduced health damage in €	14,874,516 (8,154,587 – 21,236,649)