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Research article

Assessment of health benefits related to air quality improvement strategies in urban areas: An Impact Pathway Approach

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ABSTRACT

Air pollution is, increasingly, a concern to our society given the threats to human health and the environment. Concerted actions to improve air quality have been taken at different levels, such as through the development of Air Quality Plans (AQPs). However, air quality impacts associated with the implementation of abatement measures included in AQPs are often neglected. In order to identify the major gaps and strengths in current knowledge, a literature review has been performed on existing methodologies to estimate air pollution-related health impacts and subsequent external costs. Based on this review, the Impact Pathway Approach was adopted and applied within the context of the MAPLIA research project to assess the health impacts and benefits (or avoided external costs) derived from improvements in air quality. Seven emission abatement scenarios, based on individual and combined abatement measures, were tested for the major activity sectors (traffic, residential and industrial combustion and production processes) of a Portuguese urban area (Grande Porto) with severe particular matter (PM10) air pollution problems. Results revealed a strong positive correlation between population density and health benefits obtained from the assessed reduction scenarios. As a consequence, potential health benefits from reduction scenarios are largest in densely populated areas with high anthropic activity and, thus, where air pollution problems are most alarming. Implementation of all measures resulted in a reduction in PM10 emissions by almost 8%, improving air quality by about 1% and contributing to a benefit of 8.8 million €/year for the entire study domain. The introduction of PM10 reduction technologies in industrial units was the most beneficial abatement measure. This study intends to contribute to policy support for decision-making on air quality management.

1. Introduction

Air pollution is a worldwide problem with widely known harmful effects to human health and the environment. To reverse or minimize this trend, multiple joint efforts involving government entities, organizations and citizens have been made. The strategy to reduce these negative effects, particularly in cities where the majority of the world population lives, it is to define air quality improvement policies. In this sense, European Union Member States are obligated to establish Air Quality Plans (AQPs) for their zones/agglomerations in accordance with the Air Quality Directive (AQD; EC, 2008) whenever exceedances of air quality limit values are recorded. Unfortunately, aspects beyond air quality are not addressed or quantified in the vast majority of these plans. When air quality impacts are analysed, the great research challenge lies in quantifying the intensity of the adverse effects as well as the associated costs (DEFRA, 2004). These costs are known as negative externalities, involving external costs to repair a given reference situation or avoid welfare losses. A comprehensive economic analysis starts with a clear identification of the involved air pollutants and their effects on different damage categories, including health impacts, building and material damages, crop and biodiversity losses, and ecosystem degradation (van Essen et al., 2011). Among these damage categories, health impacts caused by air pollution contribute to the largest part of the external cost

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estimates. This finding is shared by public health experts that link air pollution, even at current ambient levels, to worsened morbidity (especially respiratory and cardiovascular diseases) and premature mortality (e.g. years of lost life) (EC, 2005). Underlying these issues, a large variety of environmental factors must be previously analysed, such as overall pollution levels, characterization of emission sources (e.g. relative contribution by activity sector, geographic location and height of release points), population structure (e.g. density and spatial distribution, age groups) and the meteorological conditions influencing transport, dispersion and chemistry of air pollutants (e.g. Holland et al., 2005).

The definition of air quality management strategies can be aided by effectiveness, cost-effectiveness and cost-benefit assessments of emission reduction scenarios (e.g. Carnevale et al., 2012). Effectiveness studies assess the extent to which these scenarios result in emission reductions and associated air quality improvements. Cost-effectiveness studies assess, in addition, the monetary costs associated with the implementation of these scenarios and, hence, facilitate the identification of those scenarios that achieve emission reductions and/or air quality improvements at least cost. Finally, cost-benefit studies assess, moreover, the monetary benefits associated with air quality improvements and, therefore, facilitate the identification of those scenarios that provide largest welfare gains. Monetary costs associated with the implementation of emission reduction measures and scenarios are, generally, estimated on the basis of measure implementation rates and corresponding unit costs (e.g. following the GAINS methodology; IIASA, 2012). The estimation of the monetary benefits from emission reduction measures and scenarios is, however, more complex given the multiple, interacting and uncertain exposure/dose-response relationships as well as economic valuation issues (see Silveira et al., 2015).

This paper presents a review on the available methodologies for the quantification of air pollution-related health impacts and subsequent external costs as to, in turn, assess emission reduction scenarios designed in the research project MAPLIA (http://projeto-maplia.web.ua.pt/). To achieve this goal, the following specific objectives are established: i) identify the relevant physical health impacts and establish exposure-response functions that allow to calculate the number of attributable cases; ii) identify the different cost components related to the impacts and estimate their monetary value; and iii) use these data to assess health impacts and benefits from the implementation of emission abatement measures/scenarios in a Portuguese urban area (Grande Porto). These measures are focused on the major sources of PM10 – the air pollutant that recorded exceedances from air quality limit values established in the AQD. Finally, weaknesses and recommendations regarding the economic evaluation of air pollution impacts on human health are discussed.

2. Health impacts of air pollution

This section presents a summary description of the methodological assumptions underlying the quantification of air pollution-related health impacts (Section 2.1) and subsequent economic evaluation of corresponding damages (Section 2.2). Thereafter, an overview of research studies underpinning these methodologies is presented (Section 2.3), in particular with respect to the key impact functions and associated external costs.

2.1. Physical health impacts

Physical health impacts caused by exposure to air pollutants are expressed through morbidity and mortality indicators, related with respiratory and cardiovascular diseases. Regarding the most common air pollutants (particulate matter, ozone, sulphur dioxide and nitrogen oxides), the following health effects are frequently reported: i) reduction in life expectancy due to acute and chronic mortality; ii) chronic effects on morbidity, such as bronchitis and cough in children and asthmatics; and iii) acute effects on morbidity, namely respiratory and cardiovascular hospital admissions, asthma episodes and restricted activity. This implies three different types of cause-effect relationships, that are strongest for particulate matter (PM) as compared to other air pollutants (EHA, 2006; Pervin et al., 2008) and, thus, their effects are better documented and quantified (e.g. Mechler et al., 2002; Ruckerl et al., 2011).

The quantification of these health impacts is based on the correlation between exposure and effect, depending on the specificity and availability of data and models (Holland et al., 2005). Often, due to unavailability/lack of epidemiological studies based on country data, exposure-response functions (ERFs) are taken from international epidemiological studies that are regarded as reference studies by the scientific community. In this context, ERFs based on relative risk models have been applied to translate air concentrations into health impacts. Numerous studies show that certain vulnerable groups within a population (e.g. elderly people, children and those with underlying diseases) have a greater risk of being affected by air pollutants (Costa et al., 2014; Pervin et al., 2008; WHO, 2013a).

These ERFs may be linear or non-linear and, either or not, contain threshold exposure values. Nevertheless, the vast majority of the available methodologies assumes that the cause-effect relation is linear, in the form of a Poisson regression, which usually does not reflect the real situation as there is a threshold exposure value below which the physical impact is no longer felt. Therefore, these approaches are considered more appropriate for situations in which the increase in pollutant emissions is marginal and when the supposed linearity is not violated and, hence, the applicability domain (i.e. exposure concentration range) of the model should be clearly stated (Marques et al., 2013; Pizzol et al., 2010).

Adverse health effects occur often within a short time after exposure (short-term exposure), resulting in acute effects. Nevertheless, it is important to also consider the cumulative exposure over time (long-term exposure) that result in chronic effects (Costa et al., 2014). Short-term exposure studies usually explore time-series of hourly and daily changes in air pollution, and daily death counts or cause-specific hospitalizations (Ruckerl et al., 2011). Long-term exposure studies assess the increase in mortality risk due to chronic exposure to air pollution (Seethaler et al., 2003; WHO, 2013a). To design the overall effect of air pollution on life expectancy, cohort studies have been used to provide results in terms of changes in mortality risk (age-specific death rates) per unit change in pollutant concentration. For impact estimation, this change in mortality risk can be most reliably represented using life table methods to express mortality impacts in the target population, translated in terms of life expectancy changes and/or in total life-years gained or lost for a given air pollution scenario (Hurley et al., 2005a).

2.2. Economic evaluation of impacts

The economic valuation of health impacts arising from air pollution is, generally, based on the cost-of-illness (COI) approach (see Pervin et al., 2008; WHO, 2008). According to the COI approach, total health costs (C_{health}) are determined by the sum of direct (C_{direct}), indirect ($C_{indirect}$) and intangible ($C_{intangible}$) costs (Pervin et al., 2008):