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A multi-scale health impact assessment of air pollution over the 21st century

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HIGHLIGHTS

- We assessed impact of air pollution on health in 2030–2050.
- We used two ECLIPSE emissions scenarios (CLE, MFR) on three geographical scales.
- We projected larger impacts on CV and respiratory mortality under the MFR scenario.
- The impacts can be larger on finer scale, due to a resolution or a model choice.
- Multi-scale HIA can provide relevant results for decision-makers.

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ABSTRACT

Background: Ozone and $PM_{2.5}$ are current risk factors for premature death all over the globe. In coming decades, substantial improvements in public health may be achieved by reducing air pollution. To better understand the potential of emissions policies, studies are needed that assess possible future health impacts under alternative assumptions about future emissions and climate across multiple spatial scales.
Method: We used consistent climate–air-quality–health modeling framework across three geographical scales (World, Europe and Ile-de-France) to assess future (2030–2050) health impacts of ozone and $PM_{2.5}$ under two emissions scenarios (Current Legislation Emissions, CLE, and Maximum Feasible Reductions, MFR).
Results: Consistently across the scales, we found more reductions in deaths under MFR scenario compared to CLE. 1.5 [95% CI: 0.4, 2.4] million CV deaths could be delayed each year in 2030 compared to 2010 under MFR scenario, 84% of which would occur in Asia, especially in China. In Europe, the benefits under MFR scenario (219000 CV deaths) are noticeably larger than those under CLE (109000 CV deaths). In Ile-de-France, under MFR more than 2830 annual CV deaths associated with $PM_{2.5}$ changes could be delayed in 2050 compared to 2010. In Paris, ozone-related respiratory mortality should increase under both scenarios.
Conclusion: Multi-scale HIAs can illustrate the difference in direct consequences of costly mitigation policies and provide results that may help decision-makers choose between different policy alternatives at different scales.

1. Introduction

Numerous epidemiological studies have shown that exposure to outdoor air pollution (OAP) leads to adverse health outcomes, including increases in mortality and morbidity for cardiovascular and respiratory diseases (Beelen et al., 2013; Hoek et al., 2013; Krewski et al., 2009; Pope et al., 2002; Pope and Dockery, 2006; Raaschou-Nielsen et al.,

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2013). The International Agency for Research on Cancer (IARC) recently classified OAP (including particulate matter (PM) as a major component of it) as carcinogenic to humans (Group 1) (IARC, 2013). While individual-level health risks associated with OAP may be low compared to other risk factors, the overall population-wide public-health impact can be very large. For instance, according to the World Health Organization's Global Burden of Diseases (Lozano et al., 2012), in 2010, annually, 3.22 million people died prematurely because of outdoor PM, and 0.15 million because of ozone (O_3).

Health impact assessments (HIAs) have been extensively used to quantify the public-health impact of OAP and to help decision-makers understand the benefits that would be associated with an improved air quality (Medina et al., 2013). With the development of air quality and climate models, there is a growing interest in quantifying the future health-impacts of air pollution, taking into account trends in emissions, air-pollution policies and climate change. Joint policies to reduce emissions of air pollutants and greenhouse gases are promising, as climate and air pollutants are associated through dynamic processes at multiple scales, from common emission sources to their chemical and physical interactions in the atmosphere (Colette et al., 2012b; Jacob and Winner, 2009). HIA can help in understanding the health benefits that could potentially be achieved under different scenarios of air pollution emissions and of climate change, and therefore encourage synergies and limit trade-offs between mitigation of climate change and mitigation of air pollution.

Several HIAs examining future air pollution-related health impacts have been published using a range of climate and air quality models, scenarios, and spatial/temporal scales (Anenberg et al., 2012; Heal et al. 2012; Post et al., 2012; Orru et al., 2013). The choice of appropriate spatial and temporal scale to make such exercise meaningful to decision-makers is a crucial issue. In this paper, we present and compare HIAs of future air pollution carried out in a consistent way across three different geographical scales: the World, Europe and the French Ile-de-France (IdF) region. Our focus here is on health impacts rather than on modeling issues. The objective is two-fold: for scientists, it allows comparing the results across scales; for decision-makers, it allows putting the results into a large perspective illustrating that air quality and climate change are not only global, but also local issues.

2. Materials and methods

2.1. General framework and scenarios

To quantify the health impacts of OAP on three geographical scales we used alternative scenarios for air pollutant emissions, and climate change (Fig. 1). These emissions scenarios were inputs to climate and chemistry models, which were coupled across the scales.

We used two air pollution emissions scenarios consistent across the scales, the "Current Legislation Emissions" (CLE) and the "Maximum Feasible Reduction" (MFR). These scenarios were developed in the framework of the ECLIPSE (Evaluating the Climate and Air Quality Impacts of Short-Lived Pollutants) project (Amman et al., 2013; Klimont et al., 2013, in preparation for ACPD). They include both climate and regional air quality policies for the emissions of air pollutants. The CLE scenario assumes that the existing air quality legislation is fully implemented and enforced. The MFR assumes that all technologically feasible emission reduction measures are implemented. It is computed using the lowest range of emission factors in the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model (Amann et al., 2011) but ignores any non-technical measures. It has to be noted that while indeed the air quality policies should be mostly enforced until 2030 (Amman et al., 2013) there still might be significant changes, that is, in some world regions the activity data (e.g., economic growth) might lead to strong increases in air pollution and rebound air pollution effects unless stronger legislation is introduced. The CO_2 trajectory of ECLIPSE is similar (at a global level) to the RCP6.0 but the emission of pollutants develops differently, typically the RCPs reduce emissions much quicker than CLE in ECLIPSE/GAINS and the reasons of that were discussed in Amman et al. (2013).

From the ECLIPSE database we used anthropogenic emissions. We used Lathière et al. (2006) for biogenic emissions, Koffi et al. (2010) for the aviation and shipping emissions, and van der Werf et al. (2010) for forest and savannah burning emissions. Other source emissions were calculated within the air pollution models. For each scale, we performed two sets of continuous simulations, one for the present time and another one for the two future ECLIPSE-V4a projections. The air pollutant emissions used for the three time frames are those of 2010, 2030 and 2050 and for the sake of simplification we will use these labels in the following sections of the paper.

2.2. Climate modeling

At the global scale, we used meteorological data from the European Center for Medium-Range Weather Forecasts (ECMWF) reanalysis. To isolate the impact of anthropogenic emissions, we performed simulations under the present-day climate conditions (2005–2006). The impact of future climate change on particles and chemistry was not taken into account; we used the results of the 2006 meteorological conditions in all simulations. The role played by climate change and

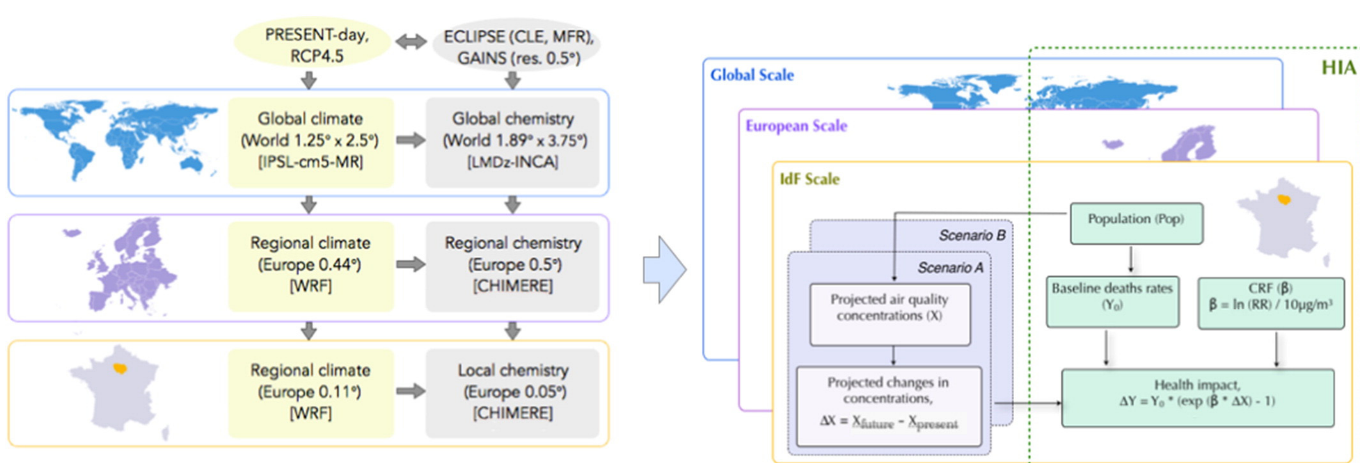

Fig. 1. The scheme of air pollution and climate modeling (left) and HIA method (right) framework: at each scale a climate model feeds a chemistry model to assess future concentrations of air pollutants, which are used in the HIA analysis. In the round brackets: (geographical area of the modeling and the size of the grid cells). In the square brackets: [name of the model].