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Better air for better health: Forging synergies in policies for energy access, climate change and air pollution

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ABSTRACT

Air pollution and its related health impacts are a global concern. This paper addresses how current policies on air pollution, climate change and access to clean cooking fuels can effectively reduce both outdoor and household air pollution and improve human health. A state of the art modeling framework is used that combines an integrated assessment model and an atmospheric model to estimate the spatial extent and distribution of outdoor air pollution exposures. Estimates of household energy access and use are modeled by accounting for heterogeneous household energy choices and affordability constraints for rural and urban populations spanning the entire income distribution. Results are presented for 2030 for a set of policy scenarios on air pollution, climate change and energy access and include spatially explicit emissions of air pollutants; ambient concentrations of PM2.5; and health impacts in terms of disability adjusted life years (DALYs) from both ambient and household air pollution. The results stress the importance of enforcing current worldwide air quality legislation in addressing the impacts of outdoor air pollution. A combination of stringent policies on outdoor air pollution, climate change and access to clean cooking fuels is found to be effective in achieving reductions in average ambient PM2.5 exposures to below World Health Organization recommended levels for a majority of the world's population and results in a significant decline in the global burden of disease from both outdoor and household air pollution.

1. Introduction

Adverse health effects of air pollution (both outdoor (ambient) and household related) have drawn considerable attention over recent years with increasing epidemiological evidence for cardiovascular, asthmatic and other health related outcomes (Dockery et al., 1993; Pope et al., 2002). In spite of legislated air pollution policies in many countries, recent studies estimate that 80% of the world's population continue to be exposed to ambient pollution that far exceeds the WHO recommended Air Quality Guideline (AQG) of 10 $\mu g/m^3$ for long-term PM2.5 concentration levels (particulate matter with aerodynamic diameter smaller than 2.5 μm) (Van Donkelaar et al., 2010; Rao et al., 2012; Brauer et al., 2012). In addition, while evidence of the high pollutant emissions and exposures resulting from the poor combustion efficiency of traditional biomass systems is well established as a major contributor to household (indoor) air pollution in developing countries (Smith and Haigler, 2008), recent studies also indicate potentially significant implications for ambient air quality (Zhang et al., 2000). More recent estimates indicate that outdoor and household air pollution are globally among the leading causes of mortality and morbidity related outcomes (Lim et al., 2012).

As a policy response to growing concern over air pollution, OECD countries have already implemented stringent air quality controls for ambient air quality and many large developing countries are increasingly following suit (Klimont et al., 2013). Economic growth has also led to an improvement in the quality of available fuels and technologies in developing countries (Stern, 2006; Dasgupta et al., 2001; Smith et al., 2005). However, emissions from cooking stoves continue to be a major component of global anthropogenic particulate matter (e.g., (UNEP/WMO, 2011)) in particular in developing countries, for e.g., in Africa and South Asia where emissions from cooking stoves are well over 50% of anthropogenic sources (Bond et al., 2004a, 2013). Improved access to modern energy services including cleaner-combusting and more efficient cooking fuels like LPG, biogas, natural gas and

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advanced biomass stoves for developing country households is also on the policy agenda of many countries and has received an impetus through the newly launched initiative of the Secretary-General of the United Nations toward "Sustainable Energy for All" (http://www.sustainableenergyforall.org/) and the Global Alliance for Clean Cookstoves (http://www.cleancookstoves.org/). Several measurement campaigns have evaluated the performance of improved stoves and fuels, including the evaluation of climate relevant species (e.g., (Maccarty et al., 2007, 2010)), and the potential health benefits of their introduction (e.g., (Anenberg et al., 2012)). In addition to resulting in significant health benefits, recent assessments suggest that such residential cooking fuel and stove switching, may also have a greater potential to curb global warming by reducing black carbon emissions (Bond et al., 2013; Shindell et al., 2012). Climate change and energy efficiency related policies are additionally being undertaken in many countries and these are likely to cause energy transformations that will impact air pollution and health related outcomes in the future.

A number of recent studies have focused on co-benefits of reducing short-lived aerosols and the associated reduction in climate and health related impacts (see for example (Anenberg et al., 2010; UNEP/WMO, 2011; Shindell et al., 2012). There is also a growing body of research focusing on the public health and potential climate co-benefits of improving access to modern cooking fuels and stoves in developing countries (Bond et al., 2004b; Haines, 2007; Smith and Balakrishnan, 2009). This new scientific research is resulting in increasing public attention on these issues and pressure to forge synergies in these traditionally separate policy domains. Also highlighted by current research is the limited assessment of policy impacts and potential co-benefits, lack of integration of the short-term benefits of related policies, and a growing need for integrated analysis that combines sophisticated modeling of policies, behavior of regulated entities, atmospheric transport chemistry, climate science and health effects (see (Jack and Kinney, 2010; Bell et al., 2008) for discussion).

In this context, we examine scenarios of outdoor and household air pollution and related health impacts in 2030, given different sets of policies on air pollution, climate change and energy access which are presented in detail in the recently published Global Energy Assessment (Riahi et al., 2012). The specific goal of this paper is to assess how effective such policy combinations could be in delivering improved air quality and health related outcomes. The climate change related outcomes of these scenarios in terms of long-term radiative forcing and associated temperature change are presented in detail in (Riahi et al., 2012) and (Mccollum et al., 2013) and are not discussed here. We do not examine here the direct impacts of climate change on human health although this is an important area of research. The underlying modeling framework used in this paper has been presented in detail in (Rao et al., 2012) and combines an integrated assessment model and an atmospheric chemistry transport model for the spatial distribution of outdoor air pollution exposures globally. We explicitly model future household energy access and use by accounting for heterogeneous household energy choices and affordability constraints for rural and urban populations spanning the entire income distribution based on (Pachauri et al., 2013). We use WHO Comparative Risk Assessment methods (Ezzati et al., 2004) and include a number of updates to methodology based on recent literature to estimate both ambient and household health related outcomes of the chosen policies. Global results are presented for 2030 and include spatially detailed emissions of air pollutants, ambient concentrations of PM2.5, health impacts in terms of disability adjusted life years (DALYs) from both ambient and household air pollution, and the associated costs of policies.

2. Materials and methods

We use the IIASA integrated modeling framework similar to (Riahi et al., 2011), including the Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) (Messner and Strubegger, 1995; Rao and Riahi, 2006; Riahi et al., 2007) for deriving global scenarios of air pollutants. Sectors included are power plants, industry (combustion and process), road transport, households, waste, agriculture, and large-scale biomass burning. Estimates of a number of GHGs and air pollutants including methane (CH_4), sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), black carbon (BC) and organic carbon (OC) are derived from the MESSAGE model and further spatially detailed at a 1×1 degree resolution. We use inventory data described in (Granier et al., 2011) and an exposure-driven algorithm for the downscaling of the regional air-pollutant emissions projections based on (Riahi et al., 2011). We include in the MESSAGE model, a detailed representation of a number of air pollution policies and costs of such policies until 2030 (methodology described in (Riahi et al., 2011, 2012). We estimate global PM2.5 emissions based on the black and organic carbon emissions in the MESSAGE model, and include in addition, non-carbonaceous components from fly-ash; production; and building sources (see (Rao et al., 2012) for details).

Atmospheric concentrations of particulate matter, in particular PM2.5, are calculated with the off-line global TM5 chemistry-transport model (Dentener et al., 2005, 2006a,b; Bergamaschi et al., 2007, 2009; Fiore et al., 2009). The models and methodology and validation of the results for 2005 are explained in detail in (Rao et al., 2012; Brauer et al., 2012) and references therein. In short, TM5 uses a set of nested grids; with a state-of-the art 1×1 resolution over the continental source regions. TM5 calculates emissions of natural origin, and uses a set of gridded emissions of primary and secondary aerosols from the MESSAGE model. Gas phase chemistry is calculated in the TM5 model using a modified CMB4 (Carbon Bond Mechanism 4) mechanism, and used to compute the formation of sulfate and nitrate, which are assumed to be in thermodynamic equilibrium following the EQSAM2 (Equilibrium Simplified Aerosol Model version 2) module. Secondary organic aerosol formation is parameterized using the AEROCOM recommendations in (Dentener et al., 2006a). Using parameterizations of wet and dry removal based on (Huijnen et al., 2010), output generated for this publication consists of primary (e.g. black carbon and organic carbon) and secondary (e.g. SO_4, NH_4 and NO_3) aerosol concentrations. As outlined in (Brauer et al., 2012) and (Rao et al., 2012), aerosol concentrations in urban regions are likely to be elevated compared to rural regions within a 1×1 degree TM5 grid cell. To compute aerosol concentrations relevant for exposure of populations, an urban increment is calculated on the basis of the contribution of primary particulate matter emissions from transport, energy and industry, and high resolution information on the fraction of population living in urban regions and the underlying land area. This is similar to the approach used in other recent studies (for e.g., (Brauer et al., 2012; Rao et al., 2012)) and includes a representation of both urban and rural exposures (thus also representing effects of industrial sources and other hot spots typically located outside urban areas) in assessing total PM2.5 concentrations and related health impacts on a global scale.

Health impacts from outdoor air pollution in terms of disability adjusted life years (DALYs) are further estimated using methodology detailed in (Rao et al., 2012). We use WHO baseline scenario data (WHO, 2008) on DALYs until 2030 based on a 5% discount rate. We limit the analysis to adults over 30 years of age and use a concentration threshold range of 7.5–50 $\mu g/m^3$ for PM2.5 in this study based on (Cohen et al., 2005) and (Krewski et al., 2009)

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