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Can air pollutant controls change global warming?

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ABSTRACT

In this paper we analyze the interaction between climate and air pollution policies using the integrated assessment model REMIND coupled to the reduced-form climate model MAGICC. Since overall, aerosols tend to cool the atmosphere, there is a concern that a reduction of pollutant emissions could accelerate global warming and offset the climate benefits of carbon dioxide emission reductions.

We investigate scenarios which independently reduce emissions from either large-scale sources, such as power plants, or small-scale sources, such as cooking and heating stoves. Large-scale sources are likely to be easier to control, but their aerosol emissions are characterized by a relatively high sulfur content, which tends to result in atmospheric cooling. Pollution from small-scale sources, by contrast, is characterized by a high share of carbonaceous aerosol, which is an important contributor to global warming.

We find that air pollution policies can significantly reduce aerosol emissions when no climate policies are in place. Stringent climate policies lead to a large reduction of fossil fuel use, and therefore result in a concurrent reduction of air pollutant emissions. These reductions partly reduce aerosol masking, thus initially counteracting the reduction of greenhouse gas forcing, however not overcompensating it. If climate policies are in place, air pollution policies have almost no impacts on medium- and long-term radiative forcing. Therefore there is no conflict of objectives between clean air and limiting global warming. We find that the stringency of air pollution policies may influence the rate of global temperature change in the first decade. Afterwards climate change mitigation policies are of greater importance.

1. Introduction

In the fourth assessment report of the IPCC (Forster et al., 2007), radiative forcing (RF) from direct and indirect aerosols was estimated to be $-1.2\ Wm^{-2}$. Total anthropogenic RF was estimated to be $1.6\ Wm^{-2}$. This means that in 2005 aerosol forcing masked almost half of the total positive anthropogenic RF. The fifth assessment report (Myhre et al., 2013) introduced the concept of efficient radiative forcing (ERF), which accounts for perturbations of surface and tropospheric conditions. In this concept, total anthropogenic ERF and total aerosol ERF are estimated to be 2.3 and $-0.9\ Wm^{-2}$, respectively.

Different aerosol species have different atmospheric properties. Sulfur dioxide emissions form sulfate aerosols, which have a cooling effect. Organic carbon (OC) also has a cooling effect, whereas black carbon (BC), commonly known as soot, leads to warming. According to the last IPCC report (Myhre et al., 2013) BC is one of the major contributors to present day radiative forcing after CO_2 and CH_4. All aerosols

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have a short lifetime of days or weeks in the atmosphere. Thus, aerosol emission reduction could almost immediately influence the radiative forcing balance, leading to either warming or cooling depending on the type of aerosol that is reduced.

Around 75% of anthropogenic sulfur emissions (Smith et al., 2001) and more than half of BC emissions (Bond et al., 2004) arise in the combustion process of fossil fuels. In order to effectively control climate change, the energy system has to undergo a transformation leading to substantial reductions of CO_2 emissions. To achieve this transformation, fossil fuel use has to be reduced. Thus, when CO_2 emissions are reduced, aerosol emissions are necessarily reduced at the same time. In addition, air pollution policies are already being implemented to further reduce aerosol emissions due to health concerns. Both policies reduce aerosol emissions independently. In this study, we investigate the interplay between them.

It is already well understood that climate change mitigation policies substantially decrease air pollution (Bollen et al., 2010; Van Vliet et al., 2012; McCollum et al., 2013). The impact of air pollution policies on the climate on the other hand is less clear. Ramanathan and Feng (2008) argued that a quick removal of sulfate aerosols from the atmosphere may result in accelerated global warming. Kopp and Mauzerall (2010) state that the 2 °C target may become economically unachievable if SO_2 is reduced and BC is not. These studies suggest that there may be a conflict of objectives between air pollution policies and climate policies.

Air pollution policies focusing mainly on BC on the other hand could be climatically favorable. A number of publications have already proposed to reduce BC emissions to slow global warming (Hansen et al., 2000; Schellnhuber, 2008; Jacobson, 2010). Bollen et al. (2009) applied a cost-benefit approach and reached lower temperatures with air pollution policies than without. In their approach they focused on particulate matter only, not taking into account the cooling effects of sulfur. Two recent assessments of UNEP suggested that measures to control BC, methane and tropospheric ozone could reduce global warming by 0.4 °C (UNEP, 2011) respectively 0.5 °C (UNEP/WMO, 2011) by 2040. Shindell et al. (2012) reported a reduction of 0.5 °C by 2050, 0.2 of which could be attributed to BC. The remaining 0.3 °C is largely due to methane reductions.

Current air pollution policies have already successfully reduced sulfur and particulate matter emissions from the industry and power sector e.g. in the United States, Western Europe and Japan. In the residential sector, particulate matter emissions continue to rise in China, India, and other south-eastern Asian countries. Reducing aerosol emissions in this sector would not only reduce air pollution and indoor smoke which is thought to cause millions of premature deaths (Rao et al., 2012), but would also be favorable from a climate perspective.

In this study, we analyze the effects of aerosol emissions on climate in a detailed modeling framework of the energy–economy–climate system including a full suite of emissions. This framework takes not only the interaction between CO_2 emissions reduction due to climate policies and concurrent aerosol emissions reduction into account, but also the interdependence of different aerosol species.

An early attempt to quantify aerosol forcing was undertaken in the representative concentration pathways (RCP) framework, a set of scenarios reaching different radiative forcing levels in 2100 (Van Vuuren et al., 2011). They found a general declining trend in aerosol emissions, with more stringent climate policies leading to even lower emissions. Co-benefits for air pollution policies from climate policies have been confirmed by a number of studies (Bollen et al., 2010; Riahi et al., 2012; Van Vliet et al., 2012; McCollum et al., 2013). The analyses of integrated assessment scenarios presented by Rose et al. (2013) and Smith and Bond (2013) found a continuous decline in aerosol forcing over the course of this century, thus playing a minor role in 2100. The impact on climate change in the short and medium term is less clear. With this paper, we aim to illuminate how climate change is affected by various air pollution emission scenarios over the course of this century. To this end we use the integrated assessment model REMIND coupled to the reduced form climate model MAGICC. REMIND has a detailed energy system representation with emissions calculated technology-specific from fuel consumption and emission control measures. As a second aspect we analyze the offset of greenhouse gas forcing reductions due to simultaneous aerosol masking reductions. A third novelty of this paper is that we apply different settings of air pollution policies, targeting either large-scale sources, such as power plants, or small-scale sources, such as cooking and heating stoves. This implies a focus on sulfur when targeting large-scale sources and a focus on BC when targeting small-scale sources. We analyze the impact of these different air pollution policies on emission levels, forcing targets and temperature and rate of temperature change.

This paper is structured as follows. In Chapter 2 we describe our methodological approach and outline the scenarios. We present our results in Chapter 3, starting with an analysis of BC and SO_2 emissions. Section 3.2 studies the effects of air pollution scenarios on radiative forcing. These effects are explored in more depth in Section 3.3, where we analyze the offset of Kyoto forcing reductions by aerosol forcing. In Section 3.4 we study differences in temperature and rate of temperature change. Finally, we summarize and discuss our results in Section 4.

2. Methodology

2.1. *The REMIND Model*

For our analysis, we use the multi-regional integrated assessment model REMIND (Leimbach et al., 2010; Bauer et al., 2012; Luderer et al., 2013b). Each single region is modeled as a hybrid energy–economy system and is able to interact with the other regions by means of trade. Tradable goods are the exhaustible primary energy carriers coal, oil, gas and uranium, a composite good, and emission permits.

The economy is modeled by a Ramsey-type growth model which maximizes utility, a function of consumption. Labor, capital and end-use energy generate the macroeconomic output, i.e. GDP. The produced GDP covers the costs of the energy system, the macroeconomic investments, the export of a composite good and consumption.