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Near-term limits to mitigation: Challenges arising from contrary mitigation effects from indirect land-use change and sulfur emissions

Katherine Calvin [a,*], Marshall Wise [a], Leon Clarke [a], James Edmonds [a], Andrew Jones [b], Allison Thomson [a]

[a] Joint Global Change Research Institute/Pacific Northwest National Lab, College Park, MD, United States
[c] Lawrence Berkeley National Lab, University of California, Berkeley, United States

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ABSTRACT

We explore the implications of potentially counteractive greenhouse gas mitigation responses to carbon prices and the complications that could ensue for limiting radiative forcing in the near-term. Specifically we consider the problem of reproducing the radiative forcing pathway for Representative Concentration Pathway, RCP4.5, which stabilizes radiative forcing at 4.5 W m^{-2} (650 ppm CO_2-e) under a different terrestrial policy assumption. We show that if indirect land-use change emissions are not priced, carbon prices that can replicate this pathway in the near-term may not exist. We further show that additional complexities could emerge as a consequence of the co-production of CO_2 and sulfur emissions as byproducts of fossil fuel combustion.

1. Introduction

Limiting greenhouse gas concentrations to a prescribed level is a policy objective often articulated in international documents, such as the Framework Convention on Climate Change (United Nations, 1992). In preparation for the IPCC Fifth Assessment Report (AR5) four levels of long-term radiative forcing were identified for assessment by the climate modeling community: 8.5 W m^{-2} (1250 ppm CO_2-e), 6.0 W m^{-2} (850 ppm CO_2-e), 4.5 W m^{-2} (650 ppm CO_2-e) and 2.6 W m^{-2} (450 ppm CO_2-e) (Moss et al., 2010). The anthropogenic emissions and concentration scenarios developed to meet these targets are referred to as Representative Concentration Pathways (RCPs) (van Vuuren et al., 2011). Unlike previous scenarios assessed by the climate modeling community, three of these RCPs include explicit mitigation policies.

Bioenergy plays an important role as a renewable, potentially zero net carbon, energy resource in the mitigation RCPs. The role of bioenergy and land use is particularly important for RCP4.5 (Thomson et al., 2011), which was developed under the assumption that terrestrial carbon emissions were priced at the same rate as fossil fuel and industrial emissions. However, it is quite possible that near-term climate policy begins with carbon prices that are initially imposed on fossil fuel and industrial emissions only. Such mitigation policy regimes are known to be characterized by the problem of indirect land-use change emissions (ILUCE), where the conversion of land for bioenergy results in other land conversions, all of which have consequences on emissions. The problem of ILUCE has been explored by a variety of papers including Edmonds et al. (2003), Gurgel et al. (2007), Searchinger et al. (2008), Schmer et al. (2008), Gillingham et al. (2008), Melillo et al. (2009), Wise et al. (2009), Hertel et al. (2010), Plevin et al. (2010), and Reilly et al. (2012). Additionally, the emissions' impact from bioenergy can be exacerbated by the application of nitrogen fertilizer to enhance yields on deforested lands (Crutzen et al., 2008; Smith et al., 2012).

Forcing is also complicated by sulfur emissions, which directly and indirectly cool the Earth's surface during their relatively short residence time in the atmosphere. Sulfur emissions are a byproduct of fossil fuel use, and they are a co-product with CO_2 as well as other combustion byproducts. It is possible to limit sulfur emissions directly without limiting CO_2 emissions. In fact, sulfur emissions have come under control regimes particularly in OECD countries in order to reduce the acid deposition they cause, though sulfur emissions continue in much of the world. Fossil fuel emissions can be controlled either by reduced use of fossil fuels—substituting technologies such as wind, solar, nuclear, or other renewable forms, which have minimal sulfur emissions—or by using fossil fuels in combination with CO_2 capture and storage (CCS)

* Corresponding author at: 5825 University Research Court, Suite 3500, College Park, MD 20740 USA. Tel.: +1 301 314 6744.
E-mail address: katherine.calvin@pnnl.gov (K. Calvin).

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technologies. Either approach results not only in reduced CO_2 emissions, but also in reduced sulfur emissions.[1]

In this paper, we explore the degree to which ILUCE and sulfur emissions complicate the problem of limiting climate forcing when terrestrial carbon emissions are not considered in the climate policy. We demonstrate these issues through the construction of a scenario that attempts to stabilize radiative forcing at 4.5 W m^{-2} without a terrestrial carbon policy. This scenario was developed as part of the integrated Earth System Model (Jones et al., 2013) development effort, with the purpose of providing a contrasting scenario for the RCP4.5 scenario published by Thomson et al. (2011). Section 2 describes the modeling approach and experimental design for meeting 4.5 W m^{-2} without the terrestrial carbon policy. Section 3 describes challenges in stabilizing radiative forcing in this policy environment, focusing on near-term challenges first and then long-term effects. Section 4 describes challenges and simplifications that were required in modeling a 4.5 W m^{-2} scenario without a terrestrial policy and compares these results to the RCP4.5. Section 5 discusses the sensitivity of the results to assumptions about the climate policy architecture, sulfur emissions, bioenergy yields, and bioenergy costs. We conclude with a discussion of the analysis.

2. Approach

We use the GCAM model, the same model and version that was used to produce RCP4.5,[2] as our tool of analysis to examine a replication of the RCP4.5 path in the context of an alternative assumption regarding mitigation policy with particular attention to the near-term. GCAM is a global integrated assessment model, coupling representations of the economy, the energy system, the terrestrial system, and the climate system (Clarke et al., 2007; Wise et al., 2009). GCAM divides the world into fourteen regions, and simulates future supply, demand, emissions, and climate from 1990 to 2095 in 15-year time steps. Land allocation decisions are made based on expected profitability, meaning that land types with higher profit rates will receive larger shares of land. Profit rates depend on the price, yield, and cost of production of the product sold. Additionally, in some scenarios, we assume that land owners are paid for carbon storage and thus, profit rates will also depend on the carbon density of land and the carbon price. Because of the coarse regional resolution, we assume a distribution of profit rates and crop yields across the fourteen regions. This distribution of profit rates reflects increasing marginal costs as more land is converted to a particular land use. We assume that bioenergy is pelletized and traded globally, and explicitly include these costs based on estimates from Hamelinck et al. (2005). A more complete description of the agriculture and land use modeling in GCAM can be found in Wise et al. (2009).

In this paper, we use GCAM to construct a new scenario to compare to the RCP4.5 scenario, documented in Thomson et al. (2011), and we refer the reader to that paper for more details on its construction. In both scenarios, total radiative forcing is limited to 4.5 W m^{-2} at the end of the century.[3] The RCP4.5 scenario applies a carbon price on all anthropogenic emissions, regardless of their source, including terrestrial carbon. The new scenario, however, includes a fossil fuel and industrial carbon price, but no price on the carbon emissions from land-use change. Developing this new scenario, which we refer to as FFICT4.5, presented several challenges and ultimately required simplifications in order to be made feasible.

[1] CCS technologies presently available require removal of non-CO_2 combustion byproducts such as ash and sulfur.

[2] While GCAM is under continuous development, we use the exact version of the model used to produce the RCP4.5 in this paper.

[3] In this paper, we use the RCP definition of total radiative forcing which excludes contributions from albedo change. However, since we are exploring scenarios with significantly different land cover patterns, we do include a discussion of albedo effects at the end of this paper.

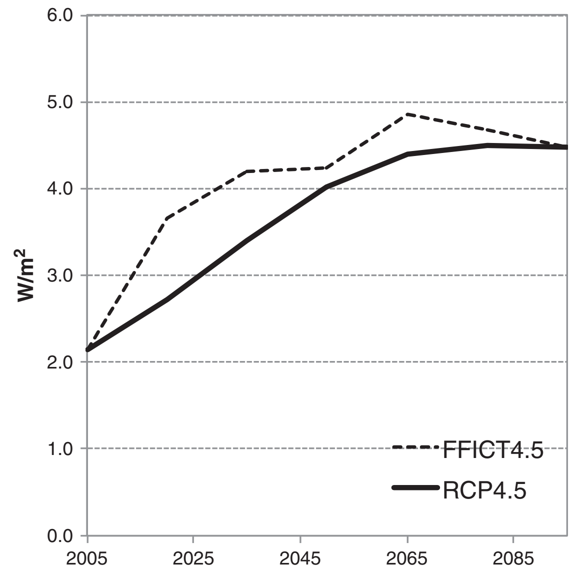

Fig. 1. Total radiative forcing in the RCP4.5 and the FFICT4.5.

3. Challenges in stabilizing radiative forcing in the FFICT scenario

A priori, it would seem a relatively simple matter to reproduce a scenario with radiative forcing limited to 4.5 W m^{-2} (650 ppm CO_2-e) as implemented by RCP4.5. In fact, counteractive mitigation responses associated with ILUCE and co-production of CO_2 and sulfur make strictly following a forcing time path difficult if not impossible. Fig. 1 shows RCP4.5 and our replication using the FFICT policy framework (FFICT4.5).

3.1. Near-term CO_2 emission reduction challenges: focus on year 2020

Two important factors are responsible for our inability to reduce radiative forcing in 2020 to levels reported by RCP4.5 in the year

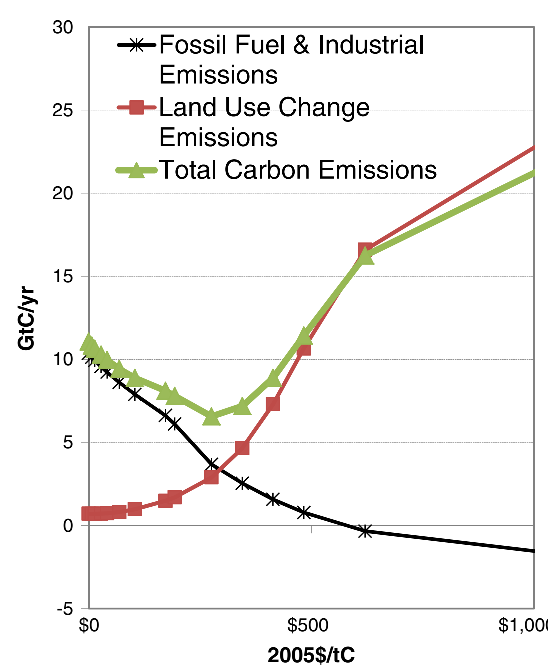

Fig. 2. Total anthropogenic carbon emissions for the year 2020 and its two components, fossil fuel and industrial emissions and land-use change emissions, as a function of the carbon price—FFICT policy assumption.