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Agriculture, land use, energy and carbon emission impacts of global biofuel mandates to mid-century

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HIGHLIGHTS

- Modeled impact of expanded global biofuels policies on energy and agriculture.
- GCAM integrated assessment model analysis of energy, land, and carbon emissions.
- Expanded biofuels policies reduce oil consumption with modest food price increases.
- Terrestrial carbon emissions eventually offset by reductions from energy system.

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ABSTRACT

Three potential future scenarios of expanded global biofuel production are presented here utilizing the GCAM integrated assessment model. These scenarios span a range that encompasses on the low end a continuation of existing biofuel production policies to two scenarios that would require an expansion of current targets as well as an extension of biofuels targets to other regions of the world. Conventional oil use is reduced by 4–8% in the expanded biofuel scenarios, which results in a decrease of in CO_2 emissions on the order of 1–2 $GtCO_2$/year by mid-century from the global transportation sector. The regional distribution of crop production is relatively unaffected, but the biofuels targets do result in a marked increase in the production of conventional crops used for energy. Producer prices of sugar and corn reach levels about 12% and 7% above year 2005 levels, while the increased competition for land causes the price of food crops such as wheat, although not used for bioenergy in this study, to increase by 1–2%. The amount of land devoted to growing all food crops and dedicated bioenergy crops is increased by about 10% by 2050 in the High biofuel case, with concurrent decreases in other uses of land such as forest and pasture. In both of the expanded biofuels cases studied, there is an increase in net cumulative carbon emissions for the first couple of decades due to these induced land use changes. However, the difference in net cumulative emissions from the biofuels expansion decline by about 2035 as the reductions in energy system emissions exceed further increases in emissions from land use change. Even in the absence of a policy that would limit emissions from land use change, the differences in net cumulative emissions from the biofuels scenarios reach zero by 2050, and are decreasing further over time in both cases.

1. Introduction

There is a substantial body of literature on bioenergy supply, use, and implications. Much of the focus in the US has been on assessing the impacts of Renewable Fuels Standard (RFS) biofuels targets on agriculture and land use [1–5]. Another area of focus has been the study of potential biomass energy supplies. The US Department of Energy recently released a major update to its Billion Ton Study of biomass energy supply potential in the US over the next two decades [6]. Fischer et al. [7] conducted a similar study to the Billion Ton Study on the biofuel production potentials of Europe, while others have looked at biofuel deployment for subregions within Europe [8,9]. Kline et al. [10] developed bioenergy supply curves for several global regions, including Latin America, China, and North America (excluding the United States), with a focus on ethanol production [11], and Yan and Lin [12] have looked at the potential for biofuel development in Asia writ large while others have studied biofuel development in smaller regions within

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Asia (see for example, [13,14–16]). There are also several studies that have researched global biomass energy supply potentials: see for example, the large body of literature summarized in IPCC [17].

Researchers at IIASA in Vienna used GLOBIOM, a partial equilibrium model of global agriculture and land use, to study the relative impact of several bioenergy alternatives under a representative biofuels policy where transportation biomass energy consumption increases from 0.6% in 2000 to 7.5% in 2030 [18]. The GLOBIOM study design is similar to that in this paper in the construction of biofuels targets, although the GLOBIOM targets are lower and nearer-term than those studied here. However, GLOBIOM is an agriculture specific model and does not model the integration between the agriculture and energy systems.

In this paper, we use the Global Change Assessment Model (GCAM, discussed in the next section), a long-term, global, integrated model with energy, agriculture and land use, and emissions included in its coverage. The study presented here is not an analysis of the ultimate potential of bioenergy supply and use, of bioenergy use under CO_2 emissions policies or targets, or of land use policies. Instead, this study is an analysis of hypothetical but specific biofuels targets: three regionally differentiated – yet global in coverage – scenarios of expanded biofuel production. The scenarios examined here range from the maintenance of biofuel policies already in place until 2050 to scenarios with expansions of biofuels policies, in terms of the amount of biofuels produced and in terms of increasing the number of regions participating. The public policy drivers and objectives for the expansion of biofuels are diverse and broad. They range from a desire to increase energy security by decreasing oil imports, to reducing greenhouse gas emissions, to the potential to raise farm incomes. What is less clear and less well documented in the literature is what would be the impact of these policies if they were extended to cover most of the world and if they were maintained for decades as opposed to years.

Based on the results of this study, we present the impact of the modeled biofuels targets on the production and use of biofuels and the reduction in crude oil. We then explore the impacts on the agriculture system including the economically-determined production of food and energy crops, crop prices, and land use by category around the world. Finally, although no carbon policy is assumed or modeled here in either the land use or energy systems, we present and discuss the long-term CO_2 emissions results of these targets as determined by GCAM. These results explicitly account for the total of direct and indirect land use emissions associated with the conversion of currently non-commercial lands into actively managed food or energy crop lands as well as emissions from fossil fuel consumption in the energy system.

2. The GCAM integrated assessment model

The quantitative analysis presented here was conducted with Version 3 of the Pacific Northwest National Laboratory's Global Change Assessment Model, an integrated assessment model that includes detailed coverage of global agriculture and energy systems, economics, and the corresponding emissions of carbon dioxide and other gases. The model's economic behavior is not that of a general equilibrium or an optimization but instead based on the concept of a recursive, dynamic market equilibrium in each model period for the included markets. In GCAM, markets are explicitly modeled for energy, agriculture and other land uses, and emissions. The model solves for the set of prices that brings supplies and demands into equilibrium in each market. GCAM is a long-term model, operating over a projected time horizon from today through 2095 and operates in 5-year time steps. Regional detail is included for 14 distinct regions: the United States, Canada, Western Europe, Japan, Australia and New Zealand, Former Soviet Union, Eastern Europe, Latin America, Africa, Middle East, China and the Asian Reforming Economies, India, South Korea, and Rest of South and East Asia [19–24].

While there are too many background modeling assumptions behind all of the scenarios to detail here, a few assumptions are worth discussing to help the reader in interpreting the results presented in this paper.[5] First, and consistent with the broad body of peer reviewed literature focused on long-term century-scale energy, economic and climate modeling, GCAM assumes growing populations and rising incomes around the world with correspondingly growing demands for food and energy (see for example, [21,25,26]). It is also assumed that the broad suite of energy, industrial, buildings, and consumer end-use technologies for meeting these demands continue to improve generally in terms of efficiency and cost (see Clarke et al. [20]). GCAM's agricultural demand modeling assumes that demands for food, with a population assumed here to grow by mid-century to about 9 billion people, will be met. In order to avoid potentially understating the impact of increasing bioenergy crop production on land use change and food prices, we make a bounding, conservative assumption that demands for food grains are completely inelastic with respect to price.[6] However, we do assume that the demand for meat has some responsiveness to price and income changes that varies by region [23]. These food and energy demands are an important determinant of the impact of bioenergy on agriculture production and prices as well as energy consumption and emissions. Another key assumption is the rate of future agricultural productivity growth around the world. Here, we follow yield improvement data from Bruinsma [27] for the first few decades, followed by modest changes thereafter as described in more detail in Kyle et al. [28] and as shown in Supplemental Information.

In GCAM, energy, agriculture, forestry, and land markets are integrated economically and physically, along with natural ecosystems and the terrestrial carbon cycle [22]. For modeling land use and agriculture, GCAM divides the world into 151 subregions based on a division of agro-ecological zones (AEZs) within each of GCAM's 14 global geo-political regions. The accompanying Supplemental Information provides more detail on the structure of the AEZs and how they are incorporated into GCAM. In terms of the analysis presented in this paper, it is worth stressing that each of these 151 subregions are distinct and their characteristics have been built up from available data – in particular the work of Monfreda et. al., [29], and GCAM discriminates among several land types based on cover and use and allow for arable lands to be further subdivide into farmlands, commercial forests, and non-commercial land uses such as forests and grasslands.

The Supplemental Information also provides a more detailed accounting of how land is allocated within GCAM to produce approximately twenty crops that are currently modeled as well as forestry products and non-commercial uses of land. In general, GCAM determines the land allocation and production of land products based on the relative profitability of competing uses of land, along with the carbon stocks and flows associated with land use and land use change. Relative profitability of among land uses depends on the productivity or yields of each use, product price, and non-land costs of production (labor, fertilizer, etc.). Product prices are determined by market equilibration of production and demand.

[5] It is not possible in this paper to fully document the GCAM model, so readers are encouraged to explore the GCAM documentation, and particularly the extensive documentation on the modeling of agriculture and land use, found at wiki.umd.edu/gcam.

[6] We do not assert that real-world price elasticities are zero. However, with non-zero elasticities, land use change, emissions, and food price increases would be mitigated by a reduction in food demand, the valuation of which is outside the scope of this analysis. Therefore, we choose the inelastic assumption as bounding.