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Economic effects of bioenergy policy in the United States and Europe: A general equilibrium approach focusing on forest biomass[☆]

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ABSTRACT

Renewable energy is an option for many countries simultaneously seeking to reduce dependence on imported petroleum and to reduce greenhouse gas (GHG) emissions that contribute to climate change. Forestry can play a role in environmental policies, such as renewable portfolio standards for bioelectricity, renewable fuel standards for biofuels, and forest carbon sequestration. This paper models interactions and interdependencies between bioelectricity and biofuel production, particularly from forest biomass. A global computable general equilibrium (CGE) model is used to measure the economic effects of bioenergy production from forest products, forest residues, and dedicated energy crops. The land use and emissions impacts on the global economy of revenue-neutral GHG mitigation policies are evaluated. Results show that mandated bioenergy production can substantially reduce carbon dioxide (CO_2) emissions, especially through fossil fuel substitution in the electricity sector. Although emissions reductions from bioenergy production in the transportation fuel sector are less dramatic than those in the electricity sector, biofuels also have lower emissions rates than petroleum-based transportation fuels.

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1. Introduction

What changes in global supply, demand, price, land use and greenhouse gas (GHG) emissions result from the introduction of climate and energy policies that encourage bioenergy production, particularly from forest biomass? This is the question that motivates this research.

Today, renewable energy is a desired option for many countries to simultaneously reduce dependence on imported petroleum and reduce GHG emissions that contribute to climate change. According to the United States Department of Energy (US DOE), bioenergy (i.e. renewable energy made from biological sources such as trees, dedicated energy crops, or waste from wood processing, agriculture, livestock, or municipalities) is considered a sustainable feedstock for the production of bioenergy [1]. The US DOE also cites a variety of woody biomass feedstocks that contain the organic polymers cellulose, hemicelluloses, and lignin, that can be converted to biofuels, bioelectricity, and biochemicals [2]. In that nearly one-third of the land area in the world was forest as of 2005, forests offer great potential for generating these lignocellulosic feedstocks [3].

In an attempt to answer the question that prompts this research, we add a variety of details to the recursively dynamic computable general equilibrium (CGE) framework of the Future Agricultural Resources Model (FARM). We include the joint production of forest, lumber, and paper residues to accurately account for the changes in price and supply for woody biomass. We introduce renewable electricity sectors, renewable transportation fuel sectors, and a dedicated energy crops sector to better account for producer demand for intermediate inputs in bioenergy production.[1] We model bioenergy policies to generate renewable certificate prices that convey the cost to subsidize renewable electricity and transportation fuels. Additionally, because land use competition

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[1] We define dedicated energy crops as non-food biomass feedstocks, such as miscanthus and switchgrass.

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between forestry, dedicated energy crops, and agriculture is an important factor in bioenergy production, we incorporate the GTAP Land Use database to further explore land use change. Greenhouse gas emissions are examined by relating the production quantity of energy sectors to carbon dioxide (CO_2) emissions using emissions factors.

1.1. Previous literature

Bioenergy is a type of renewable energy made from biological sources, whether that is dedicated energy crops, trees, or waste from agriculture, wood processing, and municipalities. According to the US DOE [4], "biomass is an attractive petroleum alternative because it is a renewable resource that is more evenly distributed over the Earth's surface than finite energy sources, and may be exploited using more environmentally friendly technologies." The Billion Ton Study [5] and the Billion Ton Update [6] examine the potential for biomass feedstocks in the United States. Specifically, forests are thought to have considerable potential for biomass production from the utilization of rotten wood from standing forest, logging residues, residues from thinning to improve forest health, direct conversion to fuelwood, and urban wood residues. Additionally, Daigneault et al. [7] find that bioenergy can be a net carbon sink if forest biomass is not limited to commercial roundwood production.

In terms of modeling the potential of bioenergy production for climate change mitigation, Hertel et al. [8] argue that land use analysis is important in climate change research because land use affects patterns and changes in greenhouse gas emissions, while climate change affects land use through changes in precipitation and temperature. The authors find that computable general equilibrium (CGE) models are better able to analyze the economics of land use because partial equilibrium models solely focus on an adjustment of prices in land-using sectors to obtain equilibrium, while CGE models are designed to examine the tradeoffs of supply and demand in the entire economy. The original Future Agricultural Resources Model (FARM) developed by Roy Darwin is described as the earliest CGE model to study land use and land cover in the context of climate change [8]. Other CGE models that have been used to analyze equilibrium effects of bioenergy production, land use change, and greenhouse gas emissions include: various GTAP models [9–13], LEITAP [14], AgLU 2x [15], USAGE [16], MIT EPPA [17], MIT IGSM [18], and ENVISAGE [19].

In an attempt to add to previous research on the subject, we include more recent renewable energy policies as well as additional disaggregated economic sectors. The EPPA model used by Reilly and Paltsev [17] is also a recursive dynamic CGE model, but modeled the Climate Stewardship and Innovation Act proposed to encourage cap and trade of GHGs in the United States. However, the Act failed to pass through the Senate in 2003, 2005, and 2007. Therefore, we model only existing renewable energy policies in the United States and Europe. In terms of agroforestry aggregation, we use 12 agricultural sectors, a forestry sector, and an additional sector for dedicated energy crops. In terms of bioenergy aggregation, unlike previous GTAP bioenergy models, we include five renewable electricity sectors and three renewable fuel sectors to give detail on potential sources of bioenergy production.

2. Methods

2.1. The FARM model

The primary objective of this research is to examine the global supply, demand, prices, land use, and GHG emissions impacts of bioenergy production. We use the FARM model to measure the economic effects of forest and energy crops used for fossil fuel substitution. We find that a recursive dynamic CGE model is well suited for the analysis of bioenergy production because it captures the economy-wide effects of climate change policies that encourage renewable energy production. Dynamic CGE modeling also accounts for the fact that climate change policy and GHG emissions are not static in time, and adjust to changes in regional economic output. For example, the United States and the European Union (EU) both have energy policies that change over time by instituting various annual targets for renewable bioenergy. A recursive dynamic model can account for these policy shifts.

The FARM model is based on the GTAPinGAMS model, which allows users of the Global Trade Analysis Project (GTAP) database to utilize the General Algebraic Modeling System (GAMS) in CGE modeling [20–22]. However, there are several important differences between the basic GTAP trade model, the GTAPinGAMS model, and the FARM model used here. First, the static model is converted into a dynamic model for FARM.[2] The trade balance, income balance, and zero-profit equations of a static model are used in a recursive dynamic framework to solve for each time period in 10-year time steps. Second, the linear expenditure system (LES) replaces constant-elasticity-of-substitution (CES) functions of consumer demand. Third, FARM's production systems allow for joint products. Fourth, the FARM model introduces six land classes for agriculture and forestry production based on agroecological zones (AEZs). Fifth, the FARM model also introduces additional electricity and transportation fuel generation technologies [23].

2.2. Data sources

The primary data source in the FARM model is the Global Trade Analysis Project (GTAP) version 7 database for the base-year 2004 [24,25]. The database contains complete bilateral trade information, transport and price linkages across regions with input–output databases for individual countries that account for intersectoral linkages within world regions [26]. The FARM model aggregates the GTAP database into 13 regions and 38 economic activities. The FARM model also utilizes the GTAP Land Use database to include additional detail on global land cover, land use, and forests. The energy data in the FARM model come from detailed energy balances compiled by the International Energy Agency (IEA) [23]. The energy balances supplement original GTAP trade data and input–output tables.

2.3. Wood residues as joint products

Wood residues are important in bioenergy production. According to the Food and Agricultural Organization (FAO) [27], the forest, lumber and paper industries already use their own wood residues for energy production. In the case of forest residue, as much as 60% of the total biomass on a harvest site is left to decompose on the forest floor, which could make forest residues an attractive source of energy. The same FAO study found that in the lumber industry, up to 55% of log input is left as waste after sawmilling. Most modern lumber and pulp mills convert these waste products into energy and within the United States, for example, this energy constitutes the largest share of renewable energy [28]. The

[2] An aggregate capital stock is assigned to each world region in the model base year, which is calculated as a function of the base-year interest rate, average capital lifetime, and base-year payments to owners of capital. The aggregate capital stock is updated each time step through investment and depreciation. The model has no forward-looking behavior, but a representative consumer in each region sets aside a fixed fraction of income for investment in future capital.