Energy Policy 55 (2013) 454–466

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Why large-scale bioenergy production on marginal land is unfeasible: A conceptual partial equilibrium analysis

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HIGHLIGHTS

- ► Land-use in bioenergy scenarios analyzed with simple transparent equilibrium model.
- ► Critical parameters identified by a detailed characterization of the model.
- ► Critical issues for land-use competition are analyzed under distinct policy cases.
- ► Extensively produced crops are twice as much affected as intensively produced crops.
- ► Bioenergy is unlikely to ever be produced on a large scale on marginal land.

ARTICLE INFO

Article history:
Received 25 January 2012
Accepted 8 December 2012
Available online 10 January 2013

Keywords:
Land-use competition
Bioenergy
Marginal land

ABSTRACT

A transparent and conceptual partial equilibrium model of global land use is used to explore long-term effects of large-scale introduction of bioenergy, under different policy cases. The transparency of the model, and the consideration of clear-cut policies, provides a clear picture of how main mechanisms of land-use competition work, and how they influence the food and bioenergy systems. The model is subjected to a detailed characterization, in which parameters critical to the results and conclusions are detected and their impacts depicted. A large-scale introduction of bioenergy would raise food prices in all cases/scenarios investigated, and relative price increases of extensively produced crops would be at least twice as high as compared to intensively produced crops. Banning production of bioenergy from the most productive land (limiting production to "marginal land") would reduce this price impact. However, we show that bioenergy is unlikely to ever be produced on any commercial scale only on land of low productivity. The economic incentives would be strong for owners of more productive land to grow bioenergy anyway and out-compete the more costly production on low yielding land. Large-scale deforestation would become attractive in response to increased bioenergy demand, especially for extensive production systems such as grazing.

1. Introduction

Bioenergy has during the last decades been promoted as an option for mitigating climate change by substituting for fossil fuels. It has also been seen as a way of reducing society's dependence on oil, which is an economically fundamental—but finite—resource. In 2007–2008, however, food prices started to increase significantly, at the same time as EU and USA increased their consumption of bioenergy, and a discussion of potential drawbacks of bioenergy began, regarding its climatic effects, food-price implications and land-use competition, the latter implying increased incentives for deforestation. Ciaian and d'Artis Kancs (2011) explain how some of these mechanisms work and they illuminate the large differences between estimates for bioenergy's role in the food-price hike that vary between extremes such as 3% according to the USDA and 75% according to the World Bank. There are many other studies with results in between the two extremes presented here.

The negative aspects of bioenergy's climatic effects are mainly due to direct land-use change (LUC) where vegetation and soil carbon stocks are changed due to bioenergy plantations on land with high carbon stocks (see e.g. Fargione et al., 2008; Gibbs et al., 2008; Lapola et al., 2010) and from indirect land-use change (ILUC), where market effects lead to vegetation and soil carbon stocks being changed (mainly due to deforestation) elsewhere (see e.g. Barona et al., 2010; Chakravorty et al., 2010; Hertel et al., 2010; Lapola et al., 2010; Searchinger et al., 2008). Calculating the

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0301-4215/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2012.12.036

carbon balance from LUC is relatively straight forward, but estimating ILUC and food-price effects is very complicated and results vary significantly between studies, depending on different system boundaries, perspectives and approaches. Examples of modeling efforts to estimate these effects can be found in Choi et al. (2011), Gillingham et al. (2008), Havlík et al. (2011), Hertel et al. (2010), Johansson and Azar (2007), Melillo et al. (2009), Schneider et al. (2007), Searchinger et al. (2008), and in e.g. Di Lucia et al. (2012) and Prins et al. (2010) there are comparisons between a number of ILUC studies and their results.

A commonly suggested solution to these adverse effects is to limit bioenergy production to land of marginal productivity (e.g. Achten et al., 2012; Biswas et al., 2010; Campbell et al., 2008; Francis et al., 2005; Shinoj et al., 2010; Tilman et al., 2006; Zhuang et al., 2011), but in this paper we show that such a policy is not likely to work due to very strong economic incentives working against bioenergy on land of low productivity.

Short-term fluctuations in food prices caused by increased bioenergy demand—and their connections to deforestation rates—are highly volatile and sensitive to market speculation, but the lower boundary of the long-term trend can be expected to mainly depend on land-use competition, since productive land is one ultimately limiting factor for agricultural produce. Water availability of course also plays an equally important role, but can be viewed as a characteristic of land and thus part of its intrinsic productivity level. Crops (and other land uses) compete via land rent, where each land owner leases out his/her land to the crop that can support the highest rent. Land rent has been extensively studied during several periods in the last two centuries and mainly when there has been a pressing social land-use related issue at hand (Haila, 1990). Among the first to study land rent was Adam Smith, followed by David Ricardo (e.g. Buchanan, 1929; Ricardo, 1821; Stigler, 1952), Johann Heinrich von Thünen (e.g. Beckmann, 1972; Heijman and Schipper, 2010) and later by Karl Marx (Haila, 1990). They all had slightly different perspectives with Ricardo focusing on productivity of land, von Thünen on location and Marx on the interaction between the land owner and the user of land. Their theories have been further developed in the second half of the 20th century, see Haila (1990) for a discussion. Haila (1990) also describes how much of the discussion on land rent in later decades has centered around whether these old theories still are valid or if more modern approaches are needed.

The treatment of potential impacts from large-scale bioenergy production has mainly been done with partial equilibrium (PE) models (e.g. Chen et al., 2011; Chakravorty et al., 2010; Gillingham et al., 2008; Havlík et al., 2011; Johansson and Azar, 2007; Schneider et al., 2007; Searchinger et al., 2008; Steinbuks and Hertel, 2012) and computable general equilibrium (CGE) models (e.g. Gurgel et al., 2007; Melillo et al., 2009), which to some extent may be regarded as new and more modern approaches. These models are based on equilibrium economics and focus on quantifying price and/or greenhouse gas (GHG) impacts from a perturbation over time (e.g. increased bioenergy demand) compared to a given baseline scenario of development. Their main mechanisms are based on the same microeconomic theory as the simpler models developed by Smith and Ricardo etc., even though they include much more detail and optimization over time. These models with high levels of detail are normally used to produce detailed scenarios—often also spanning long time horizons.

Such scenarios are based on parameters that can be expected to be valid only under very small perturbations (Hertel, 2010, p. 45). Current trade flows and prices will probably change over the coming century, which means that perturbations are expected to be large for long time scales. There are already significant deficit in empirical data and thus uncertainties in parameter values for the current situation, as e.g. is brought up by Berry (2011) regarding yield response elasticities, and uncertainties of course increase with distance into the future. An example of how such uncertainty affects results, is that Hertel et al. (2010) made a study, much resembling the highly cited study by Searchinger et al. (2008), but with some different assumptions, and got results in the order of one fourth the impact of what Searchinger et al. (2008) did.

These highly detailed models (PE and CGE, mentioned above) may thus have the potential to perform well for questions related to small increases in demand for bioenergy during some years ahead, but do they offer valid answers for questions regarding the introduction of large-scale bioenergy systems on time scales in the order of several decades into the future? Detailed scenarios give the impression of a high degree of reliability, even though they only present one (or a few) possible development(s) out of a near infinite number of possibilities. At such time scales it is much harder to say anything regarding prices, policies and limitations of production, except at physical and biological levels, where things can be excepted not to change all that much. A genuine understanding of underlying physical mechanisms is probably more useful than detailed predictive efforts when the underlying economic and political system can be expected to change. There are, however, potentials for relatively large changes also in physical and biological conditions from new (e.g. genetically modified) crop varieties; technological changes in agricultural practices; and impacts from climate change, but the net effect of these changes are highly uncertain. See Smil (2006) for a discussion of previous predictive failures in the context of energy system transitions, where preferences and political decisions have had large influences.

There has—as far as we know—not been any serious effort to treat this food vs. fuel vs. forest (and climate) dilemma by using a simple and conceptual model based on physical constraints that does not aim at a high level of detail, but rather at capturing and displaying main land-competition mechanisms in a transparent manner. Hertel (2010) has developed a conceptual land-use model, that shows how different factors influence price effects over the long run from changes in demand etc. That model is—in contrast to the one presented here—based on sums of elasticities of extensive and intensive margins and only indirectly on a physical representation of land. The advantage of a simple approach is that important mechanisms and their effects are more easily distinguished and understood when details are few, than in highly detailed models. A simple model based on physical constraints may be able to offer some insights to potential lower boundaries of price changes in the long term from large-scale introduction of bioenergy. Even if such results are crude, they offer results with higher transparency of how critical parameters affect the outcome, than similar estimates from more detailed models. The crudeness of the results conveys less an impression of precision at the quantitative level, than does a precise scenario.

We argue that an understanding of important mechanisms and long-term characteristics of this global land-use system is fundamental for policy support. Decisions regarding large-scale introduction of bioenergy concern long time scales and involve very large perturbations to the agricultural system and to trade flows. Once decision makers have understood the long-term constraints and their implications, they can be expected to make better use of detailed scenarios developed by larger models and use these to construct short-term policies in accordance with long-term goals.

The purpose of this paper is to produce qualitative pictures—and system-behavioral insights—of economic impacts from competition for land from large-scale bioenergy production by applying the conceptual land-use model developed by Bryngelsson and Lindgren (2012). This is done in a number of conceptual scenarios for