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The trade-off between bioenergy and emissions with land constraints ☆

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HIGHLIGHTS

- ► Biofuel pathway rankings differ depending on the functional unit of measure.
- ► Conventional life cycle analysis overlooks the opportunity cost of land.
- ► Including a land constraint, a model is developed to determine pathway optimality.
- ► The optimization model suggests emissions be measured per hectare.
- ► Switchgrass and corn are modeled as competing alternatives for biofuel production.

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ABSTRACT

Agricultural biofuels require the use of scarce land, and this land has opportunity cost. We explore the objective function of a social planner who includes a land constraint in the optimization decision to minimize environmental cost. The inclusion of this land constraint in our optimization model motivates the measurement of emissions on a per-hectare basis. Switchgrass and corn are modeled as competing alternatives to show how the inclusion of a land constraint can influence life cycle rankings and alter policy conclusions. With land use unconstrained, ethanol produced from switchgrass is always an optimal feedstock relative to ethanol produced from corn. With land use constrained, however, our results show that it is unlikely that switchgrass would be optimal in the midwestern United States, but may be optimal in southern states if carbon is priced relatively high. Whether biofuel policy advocates for one feedstock over another should consider these contrasting results.

1. Introduction

The environmental ranking of biofuel pathways that one obtains based on a measurement of emissions per liter is not necessarily the same as one would obtain after accounting for differences in energy yields per hectare. For example, according to the Environmental Protection Agency (EPA), switchgrass used for production of cellulosic ethanol leads to a 110% reduction in GHG emissions (Environmental Protection Agency, 2010a). Corn grain ethanol leads to a 21% reduction.[1] It would seem that switchgrass is certainly the more environment-friendly of the two choices. However, if the quantity of gasoline displaced by production of ethanol from a hectare of corn grain plus corn stover is sufficiently greater than that displaced from a hectare of switchgrass, it is conceivable that corn could be the environmentally superior feedstock choice on a per-hectare basis. Although demonstrated here with corn and switchgrass, this same concept of potentially inconsistent per hectare emissions rankings is valid when comparing any single energy crop with a crop that generates multiple types of energy from the same unit of land.

Inconsistent per hectare emissions rankings may become more pronounced if there is an additional benefit to biofuel production beyond that associated with carbon. Assuming for the moment that corn yields more energy per hectare than switchgrass, then more value derived from biofuel production results in a higher opportunity cost of choosing to grow switchgrass. Thus, even though switchgrass has a substantially better carbon profile per liter than corn, there is a point at which it is not optimal from a social planner's perspective to choose switchgrass for production of biofuels if corn (both grain and stover) is available as an alternative feedstock. This could be due to either low carbon prices or high external benefits to biofuel production.

Deriving value from two sources on the same unit of land is not a new concept in agriculture, but it has not been adequately

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[1] The EPA conducts this analysis under three time horizon scenarios: 2012, 2017, and 2022. The numbers reported here come from the 2022 scenario.

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represented in a life cycle emissions setting. Farmers that choose to harvest corn for silage attribute value to both the grain and the stover on the same unit of land. The same is true in ascribing value to the production of soybean oil and soybean meal from one hectare of soybeans. The value of both of these commodities is embedded in a farmer's decision to grow soybeans. Moreover, in deciding whether to grow soybeans or corn, a farmer also takes into account per hectare yield differences across crops and would not choose to grow soybeans simply because the price per bushel is higher than that of corn. A per hectare measure of social cost, emissions, is also consistent with this logic where commonality resides in the fact that there is a fixed amount of land available to grow crops.

Some may argue that land availability is not fixed, that additional (marginal) land could be brought into production if needed (Perlack et al., 2005; Campbell et al., 2008; Cai et al., 2011). Swinton et al. (2011) have pointed out that the scope for this expansion is extremely limited while others have identified specific risks and weaknesses in producing biofuels on marginal lands (Liu et al., 2011). Pacca and Moreira (2011) seek to quantify the total amount of land that would ultimately be needed to satisfy global transportation fuel demand using Brazilian sugarcane under various efficiency scenarios. Searchinger et al. (2008) have discussed the implications of converting land (possibly forests) into cropland, resulting in ILUC emissions. While the issue of constraining the amount of land used for biofuels is quite controversial, the results of Swinton et al. (2011) and Liu et al. (2011) provide some justification to the assumption that there is a limit on the amount of land available for biofuel production. If this limit has not yet been reached, it is likely to be realized in the future as the (emissions) cost of conversion becomes prohibitively high. Within the context of the food-versus-fuel debate, there is also some recognition that there is a limit on the amount of land that should be used for biofuels in order to allow productive cropland to continue to be used to produce food and feed. This has been a motivation for the pursuit of "next generation" biofuels (Coyle, 2010).

Relative to other inputs used for biofuel production, land is also a unique input because it is not mobile, cannot be readily acquired when making production decisions, and is fixed for individual farmers when making planting decisions (as opposed to nitrogen fertilizer which can be easily acquired in large quantities). The total amount of land suitable for cropping is also fixed though many countries are not yet at their full potential.

The purpose of this article is to explore the implications of conventional agricultural life cycle assessments (LCAs) that do not consider the effects of land scarcity and the corresponding opportunity cost of feedstock choice. Our analysis thus abstracts from the current renewable fuel standard (RFS) volume mandate by instead considering land use as the binding constraint. We do not attempt to explain how land is allocated between cropland and, for example, forestland. We focus our analysis on the impact of constrained land on the allocation of cropland used for biofuel production. This allows us to highlight the policy implications of relying on analyses that suggest infinite land availability.

A two-stage optimization model is presented in which the social planner includes all internal and external costs. In the first stage, the social planner chooses the optimal amount of land to allocate to biofuel production given alternative potential uses of land. In the second stage, the social planner determines how to use the land that has been allocated to biofuel production. Our focus will be on the second stage. The second-stage optimization consists of a two-part objective function that the social planner maximizes by choosing among available biofuel pathways subject to a land constraint. The first part of the objective function is the cost associated with net GHG emissions given a price on carbon. This portion represents the environmental benefit associated with biofuel production. The second part of the objective function represents an external value associated with biofuel production that might be due to a desire to reduce dependence on imported oil. For the purposes of this study, we consider two competing feedstock choices: corn and switchgrass. In the case of corn, both grain and stover are used for production of ethanol.

The optimal solution to the social planner's problem will depend on three key factors in addition to the maintained GHG accounting framework of the EPA. These are the relative energy yield per hectare of corn and switchgrass, the price of carbon, and the external benefits to biofuel production. Even when there are no external benefits to production, the results will show that it is highly unlikely that switchgrass would be optimally chosen as a feedstock for biofuel production in the midwestern United States. It is more conceivable, however, that switchgrass would dominate corn for this purpose in southern and southeastern states. In a more realistic setting where there is an additional external benefit to biofuel production, switchgrass becomes even more unlikely to be optimally chosen outside of these regions. This is in contrast to volume-based (or energy-based) LCAs in support of the RFS volume requirements which would suggest that switchgrass dominates corn on a per-liter (or per MJ) basis.

The remainder of the article is organized as follows. In the next section, a brief background of existing biofuel policy and its connection to life cycle analysis is presented. A model is then introduced that is taken as the optimization problem that a social planner (i.e., U.S. society) would solve. Then, data and parameter assumptions required to solve the model are presented and described. The optimization problem is then solved numerically based on the defined parameter assumptions. Finally, the numerical solution to the model generates an "optimality frontier," which will be interpreted as an implied carbon price curve. The magnitudes of implied carbon prices will be used to illustrate the likelihood of switchgrass being optimal when compared to projected carbon prices. In addition to solving a general model over a range of assumptions, the model will also be solved for specific crop reporting districts for a particular set of biofuel carbon policies so as to allow for differentiated land. A discussion of the policy implications of the results is subsequently presented, and the last section of the article provides concluding remarks.

2. Background

The merits of biofuels relative to their fossil fuel counterparts often include independence from foreign oil supplies and lower greenhouse gas (GHG) emissions. That biofuels accomplish the first of these is not often disputed. The degree to which biofuels achieve the latter, however, has been vigorously debated. The controversies notwithstanding, the U.S. Congress first passed renewable fuel volume mandates in the Energy Policy Act of 2005. These mandates became known as the Renewable Fuel Standard (RFS). In 2007, the mandates were expanded through the enactment of the Energy Independence and Security Act (EISA), and the corresponding renewable fuel standards are now referred to as RFS2. In phases, EISA requires that 36 billion gallons (136 billion liters) of renewable fuel be blended into transportation fuel by 2022. In addition to the increased volume mandates, there are two key modifications to the original 2005 energy policy. The first is the disaggregation into four types of biofuels: renewable fuels, advanced biofuels, biomass-based diesel, and cellulosic biofuels. The second is the specification of GHG emission reduction thresholds for each category that must be met in order to qualify under RFS2.