A Decision Model for Economic and Environmental Impacts of the Food and Biofuel Competition

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Abstract. Rising demand for food and energy leads to debates about biofuel production from food crops. On the other hand, biofuels derived from lignocellulosic sources offer positive environmental impacts such as enriching degraded soils through carbon sequestration and prevention of soil erosion. In this study, we develop a mixed integer optimization model in order to investigate the economic and environmental tradeoffs between biofuel and food production. This model maximizes the total profit of farmers while satisfying sustainable food supply. The model provides optimal decisions regarding allocation of lands to food and energy crops, seeding time, harvesting time and amount, and budget allocations to farm operations. We have applied the model in the Kansas State by considering the production of corn and switchgrass.

1. Introduction

Rising energy demand leads researchers to find alternative ways for energy production. Having various environmental and economic benefits, biofuel is considered to be one of the best renewable alternatives for fossil fuel. There are multiple biomass sources for biofuel production, and corn (Zea mays L) is one of the most common crops cultivated in many countries. Food production from corn has been supported by the policies in the US for decades. In addition to its usage as a food source, it has been also utilized as a biomass source in ethanol production. Increasing demand for food and biofuel simultaneously leads to concerns and debates about security of food supply and sustainable energy generation. According to the renewable fuel standard (RFS-2) in 2007, ethanol made from grain can compose 15 billion out of the total 36 billion gallon ethanol yearly. In 2011, total ethanol production was about 14 billion gallons [1].

However, there is also a discussion about biofuel production claiming that ethanol production from corn requires more energy input than its output [2]. On the other hand, other researches state that ethanol production provides a net energy return [3]. Using efficient production methods and hybrid corn increased the productivity each year. Currently over 25% of corn is used in ethanol production in US [4]. Besides, subsidies in corn production cause displacement of grasslands and other crops. Using corn for ethanol production may lead to increase in food prices. There is also ethical question regarding the usage of food for biofuel production while there is still hunger.

Another source of biomass is lignocellulosic plant, particularly switchgrass (Panicum virgatum), which is native to North America and has benefits on the environment, such as soil erosion prevention, low fertilization requirement, tolerance to variable soil conditions and drought along with the enrichment of soil quality [5].

2. Problem Statement

Various land types, such as grassland, cropland, and marginal land, can be used for biomass production from switchgrass. However, there is not a study comparing opportunity cost of switching into switchgrass production in the croplands where farmers currently cultivate corn. There are operational and strategic decisions to be made in order to maximize profits of farmers while considering environmental effects and economic changes of food and biomass production from corn and switchgrass simultaneously.

In this model, we also investigates the relation of food and biomass prices and let farmers to have a projection when they allocate their lands to switchgrass and corn production for overall planning horizon. Besides, our study will clarify the profitability thresholds of both crops, land types to be allocated for biomass and food production, budget allocation to farm operations in order to maximize overall revenue of farmers. In addition, we will investigate the effects of environmental concerns on the best decisions. In this study, in order to answer the impacts of biomass production from food crops, switchgrass is considered as an energy crop due to its positive environmental impacts and low input requirements while corn is used for its high production in the US. Corn is currently being used in biofuel production.

3. Mathematical Model

In this study, we have developed a mixed-integer optimization model which involves strategic and operational decisions of food and biomass production. Employing the model, we provide optimal decisions regarding the budget allocation to farm operations, seeding time, land type allocation, harvesting amount and time, yields sold to food facilities and biorefinery simultaneously in a given region during planning horizon.

The objective of the proposed model is to maximize economic value obtained from food and biomass production as well as their environmental benefits. The environmental benefits considered in the model include reduction of GHG emission and soil erosion prevention. There is a set of constraints in the mathematical model regarding the production constraint including growth, harvesting, and demand while budget constraint includes seeding, production, harvesting, and transportation.

This study also incorporates environmental concerns in the mathematical model. Sustainability of bird population is ensured by limiting harvesting zones on grassland and marginal land while security of food supply is handled with a sustainability factor.

4. Case Study

We have applied the MILP model explained in section 3 to a real project in Hugoton city of Kansas State as a case study. Switchgrass is considered as the biomass source while it is allowed to cultivate in all land types; cropland, grassland, and marginal land. On the other hand, corn is considered as both food and biomass source while it can only be cultivated in cropland. Planning horizon is taken as 10 years.

We have developed two basic scenarios for analyzing the problem in depth: contract and no-contract scenarios. In the contract case, biorefinery has long-term contracts with for biomass supply which in return fixes the price of switchgrass and corn (stover and grain for biomass) during the planning horizon. However, in the no-contract case, all the prices of corn and switchgrass can change during the planning horizon. For the environmental analysis, we have considered different weights on the multi objective function of the model. We analyze contract and no-contract scenarios by performing sensitivity analyses on objective function as profit-based, environmental-based, and equal-based weights.

5. Conclusions

In this paper, we have developed an MILP model to analyze economic and environmental tradeoffs between food and biomass production. The proposed model has been applied in Hugoton city of Kansas State. In this application, we have considered switchgrass as energy crop for biomass production while corn is utilized for both biomass and food production. Economic and environmental outcomes of the competition between food and energy production have been analyzed by developing a set of scenarios and sensitivity analyses. Results show the effect of criteria weights, and budget on the decision variables. This study provides a general mathematical model for the best decision strategies on the farm level which can be applied in different regions by including any other food and energy crop that is available in that region.

6. Acknowledgments

This research is based upon work supported by the National Science Foundation under grant no. EPS-0903806 and the State of Kansas through the Kansas Board of Regents.

7. References

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