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Optimizing the Cost and Greenhouse Gas Emissions of Switchgrass Supply System to Biorefineries: A Case Study of Tennessee

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Optimizing the Cost and Greenhouse Gas Emissions of Switchgrass Supply System to Biorefineries: A Case Study of Tennessee

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INTRODUCTION

Producing biofuels from lignocellulosic biomass (LCB) has been suggested as a way to mitigate the dependence on fossil fuels and the production of greenhouse gas (GHG) emissions in the United States. Switchgrass, a native perennial grass in North America, has been regarded as a promising LCB feedstock for bioenergy. Tennessee Biofuel Initiative, a state-funded program, has committed $70 million to develop the local LCB-based energy industry. More than 5,000 acres of switchgrass land and a pilot biorefinery have been established since 2007. A commercial-scale biorefinery is envisioned in the near future in Tennessee.

Both economic and environmental performance of switchgrass supply chain can potentially impact the sustainability of the emerging bioenergy industry. Since some factors such as land conversion and feedstock transportation have an effect on both the economic cost and GHG emissions, a trade-off might exist between these two objectives if one factor has a positive impact on cost [GHG emissions] while a negative influence on GHG emissions [cost]. This information is important since it can help both the government and investors develop a more balanced and sustainable bioenergy sector in the state and the southeastern region.

OBJECTIVES

1. Determine the key factors affecting the costs and GHG emissions in a optimal switchgrass supply chain including production, harvest, storage and transport of the feedstock.
2. Identify the location of biorefinery and feedstock draw area associated with the optimal switchgrass supply chain.
3. Analyze the potential trade-off between the economic and environmental performance of the energy crop supply chain.

ANALYTICAL MODEL

A multi-objective geospatial mathematical programming model was developed to search for the Pareto-optimal solutions between cost and GHG emission in the supply chain of switchgrass in Tennessee. The location of the biorefinery plant and associated feedstock draw area in Tennessee was also determined through applying the multi-objective model to high resolution spatial data.

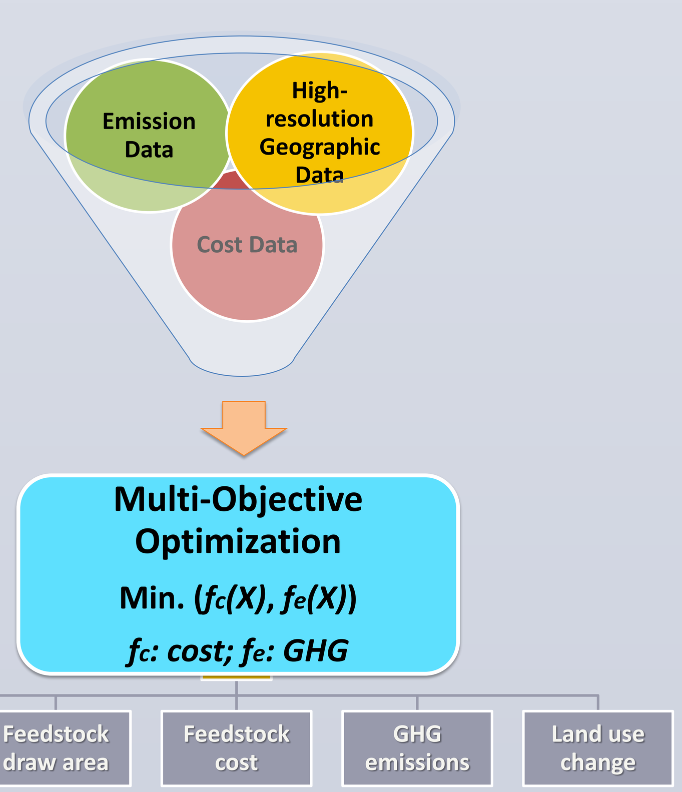

Figure 1. Model framework

MODEL ASSUMPTIONS & DATA

- Capacity of a commercial-scale and single-feedstock biorefinery is 50 million gallons of biofuel per year.
- Potential locations for the biorefineries are limited to feasible industrial parks in Tennessee with access to water, power, and roads, as well as sufficient storage space (see Figure 2).
- Feedstock supply regions are cropland in Tennessee and the 50-mile buffer from the state border. The resolution of crop zone is 5 square miles.
- Switchgrass harvested once per year during November-February.
- Dry matter loss during storage up to 365 days are considered.
- Crop yields are obtained from USDA/NASS and adjusted to the sub-county level using the SSURGO database, while switchgrass yield is estimated by Oak Ridge National Lab.

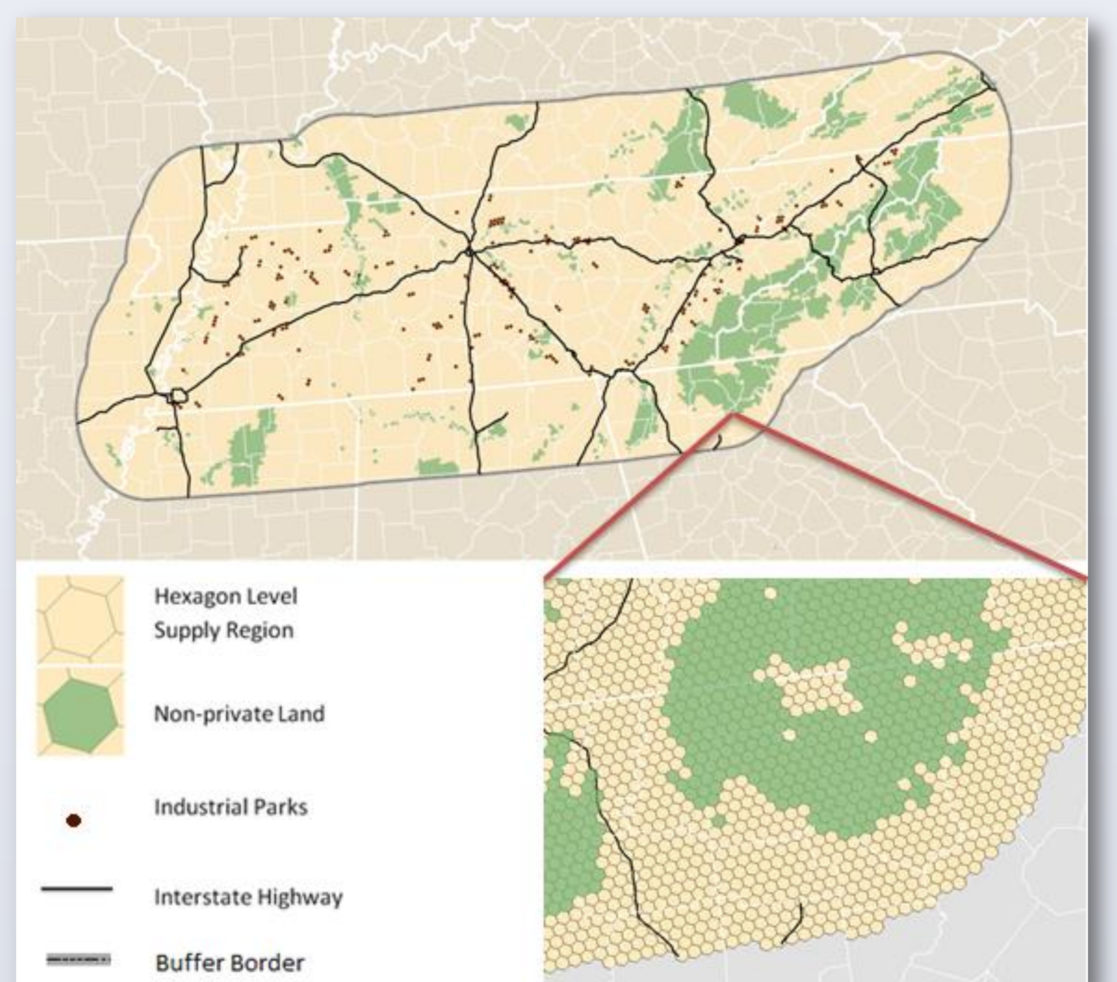

Figure 2. Study area

Table 1 summarizes the components of cost and GHG emissions in the switchgrass supply chain considered in this study.

Table 1. Cost and GHG Emission from Switchgrass Supply Chain

	Economic Cost	GHG emissions	
		Direct	Indirect
Land Conversion	Opportunity Cost	Land use change	
Production	• Establishment • Annual maintenance	• N fertilizer application • Fuel usage	• Fertilizer production • Equipment production
Harvest	• Farm equipment: Fuel Labor Maintenance Ownership	• Fuel usage	• Equipment production
Storage	• Labor • Pickup fuel • Covers and Pallets	• Fuel usage • Storage emission	
Transportation	• Labor • Fuel • Truck ownership	• Truck emission	• Truck production

EMPIRICAL RESULTS

Figure 3 presents the possible outcome from the multi-objective optimization and the Pareto optimal curve that shows the trade-off between the improvement in cost and GHG emissions. Three potential candidates for biorefinery on the Pareto curve are highlighted: the cost minimal candidate A, GHG emission minimal candidate B, and an alternative optimal candidate C considering the balance of both objectives.

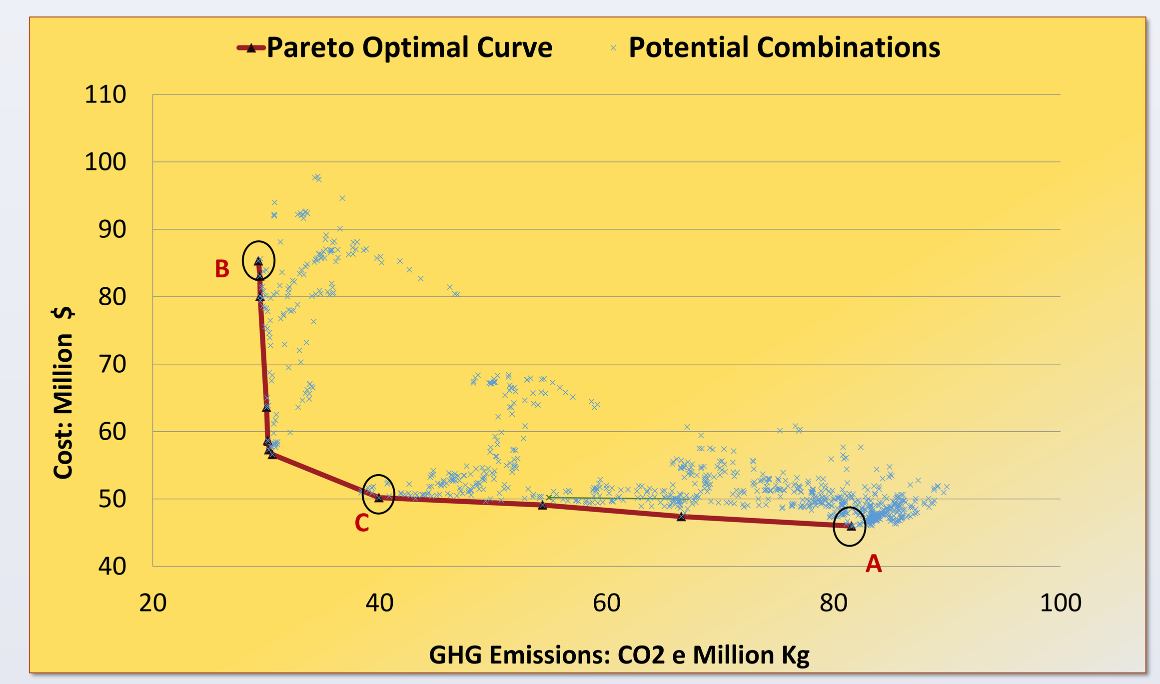

Figure 3. The Pareto-optimal curve and three candidate sites (A: cost minimal; B: GHG emission minimal; C: alternative optimal)

Figure 4 summarizes economical and environmental performance of the three optimal sites selected in Figure 3. Results show that:

- For the cost-minimal site A, the total cost of the supply chain was near $46 million and the GHG emissions were above 81,000 CO_2e ton.
- When GHG emissions were minimized in the site B, GHG emissions were reduced by 64% from the level in the site A, whereas the cost of the switchgrass chain nearly doubled.
- For the alternative optimal site C, the cost of its switchgrass supply chain was about 9% higher when comparing to the site A; while the associated GHG emissions were cut to more than half.
- Similarly, comparing to the site B, the GHG emissions in feedstock supply system for the site C were 27% more but the related cost was 41% less.

Figure 4. Comparison of the cost and GHG emissions of the three candidates (A: cost minimal; B: GHG emission minimal; C: alternative optimal)

Figure 5 shows the relevant feedstock draw areas and the land use changes for the three optimal sites in Figure 3. We found that:

- Candidate site A, the cost minimal site, was located in Rutherford County. The majority of the supply region was converted from pasture/hay land while a small portion was from crop land.
- Candidate B, under GHG emission minimization, was suggested to be located in Obion County with the entire feedstock supply was converted from cropland.
- Candidate C, taking into account both objectives, was located in Haywood County with 16% of the feedstock acreage was converted from hay land.
- The output is related to the land use change by crop type. Land conversion from pasture/hay to switchgrass had a low opportunity cost while crop-to-switchgrass was expensive. In contrast, pasture/hay had higher soil carbon sequestration rates than switchgrass while all other crops had lower carbon sequestration rates.

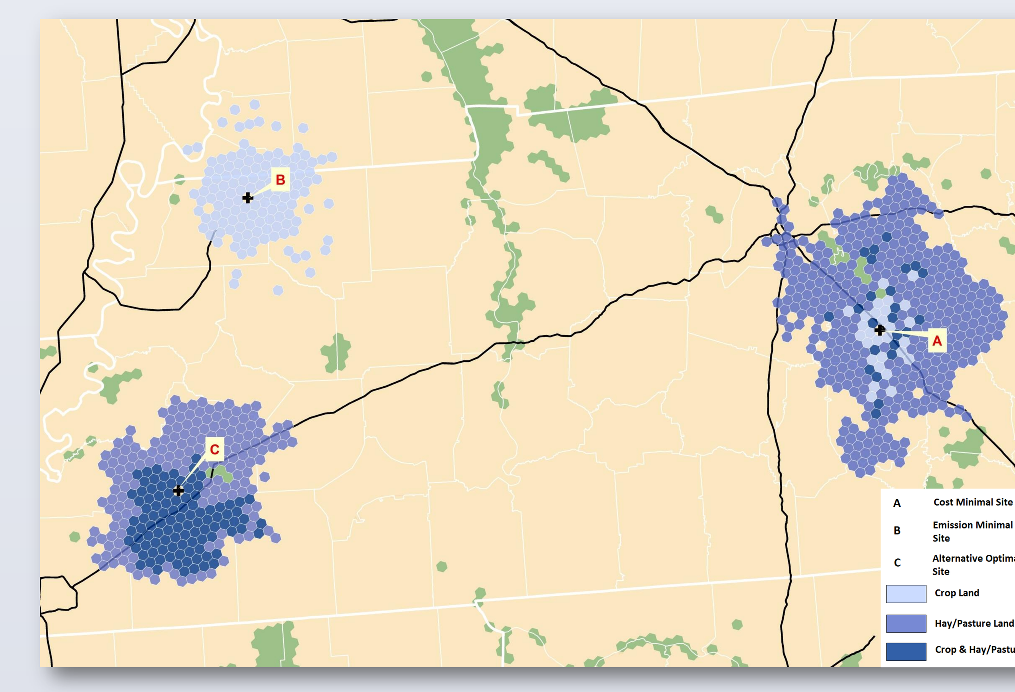

Figure 5. Switchgrass draw area and land use change for the biorefinery at the three candidates

CONCLUSIONS

This study evaluated a switchgrass supply chain in Tennessee considering both economic cost and GHG emissions in the optimization objectives. Our findings suggest that:

- Differences among the profitability of crops replaced by switchgrass and soil carbon sequestration rates are the primary factors to the tradeoff between cost and GHG emissions.
- Choosing the type of land conversion can achieve high economic efficiency with more GHG emissions, or less GHG emissions with higher economic cost.
- The Pareto curve derived from this study implies that the location of switchgrass production and the resulting changes in crop production should be considered in targeting government incentives to encourage switchgrass-based biofuel production in the state and the southeastern region.

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