THE EFFECTS OF OPPORTUNITY COSTS, SUPPLY CHAIN LOGISTICS AND CARBON BALANCES ON ADVANCED BIOFUEL PRODUCTION

Aaron V. De Laporte

Department of Agribusiness and Applied Economics, North Dakota State University,
Department 7610, PO Box 6050, Fargo, North Dakota, United States of America, 58108-6050.
Email: aaron.delaporte@ndsu.edu. Phone: 701-231-8672. Fax: 701-231-7400.

David Ripplinger

Department of Agribusiness and Applied Economics, North Dakota State University,
Department 7610, PO Box 6050, Fargo, North Dakota, United States of America, 58108-6050.
Email: david.ripplinger@ndsu.edu. Phone: 701-231-5265. Fax: 701-231-7400.

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ABSTRACT

Changes in crop prices have encouraged farmers to consider alternatives, such as potential advanced bioenergy feedstocks, including energy beets. This paper employs an integrated biophysical, economic and GIS-based transportation model to examine the supply of beet-bioethanol from five sites in North Dakota. The study finds that beet bioethanol could provide net benefits to farmers and ethanol producers in the state, under current market conditions, but only if the bioethanol plant site is carefully selected. More specifically, a 20,000,000 gallon ethanol plant in Valley City could have net returns of $436,049. This plant would acquire 760,000 tons of beets from around the plant site and further east toward the Red River Valley from 22,682 acres of cropland an average distance of 15.7 miles away. The average yield of the selected cropland is 33.5 tons/ac with average net farm returns of $26.09/acre above opportunity costs. Opportunity and transportation costs can substantially change the attractiveness of croplands for beet production. The current market opportunity presented by beet bioethanol at $1.50/gal ethanol is not particularly attractive, but as ethanol prices increase, this opportunity could become attractive at a number of sites throughout the state.

KEYWORDS

Energy Beets; Bioenergy Supply; Bioethanol

1. INTRODUCTION

Declines in crop prices have led farmers to consider alternatives to their current cropping practices, including the introduction of dedicated energy crops. The Energy Independence and Security Act of 2007 (EISA) sets mandates for conventional and advanced biofuel use. Certain advanced biofuels have had limited commercial scale success, in part because of limited feedstock availability. One crop that shows promise as an advanced biofuel feedstock is the sugar beet (beta vulgaris).

North Dakota and Minnesota account for more than half of domestic sugar beet production. While nearly all of the beets grown are used to make refined sugar, additional beet production in new areas of the region could provide a feedstock for advanced biofuels and enhance farmer returns. Sugar beets grown for biofuel production, so called 'energy beets', could require less demanding processing compared to refined sugar, decreasing production costs. However, as a new crop, energy beet supply chains do not exist and have not yet been rigorously designed and optimized.

Two likely energy beet supply chain alternatives exist. In one case, energy beets could be stored in-field and directly shipped to local ethanol refineries. Alternatively, beets could be shipped to a regional storage depot then moved to the refinery for later processing. Volatility in fuel prices and transportation costs may impact one supply chain more than the other.

A host of spatial factors effect supply chain costs, including yields and transportation distances. The opportunity costs of energy beet production, relative to dominant cash crops such as corn and canola, are important considerations. The environmental benefits of ethanol production from energy beets, including carbon impacts, and nutrient and soil health, are also important.

In the context of advanced biofuels, volatile energy prices, unevaluated supply chains, opportunity costs and environmental benefits, the purpose of this paper is to estimate the supply of energy beet-bioethanol in North Dakota under different price assumptions, using an integrated economic, environmental and GIS analysis, and to inform bioenergy policy in the state and nationally.

This paper employs an economic and environmental GIS-based model that maximizes the profit of potential ethanol plants situated in five North Dakota cities as determined by beet and ethanol prices with an emphasis on transportation costs. The model incorporates spatial considerations of beet yields and production costs, including agricultural opportunity costs, and transportation and logistics schedules.

2. METHOD

2.1 THEORETICAL MODEL

Bioenergy production is driven by prices in many commodity sectors. The price of agricultural commodities will negatively correlate with bioenergy crop production as the opportunity costs rise. As the price of ethanol rises, the price paid for energy beet feedstock should rise, making bioethanol production more attractive. For energy beet production to occur, the price of beets must allow net revenues to exceed opportunity costs – beets must become the best alternative for the farm. For this to be the case, the tradeoff between yields and transportation costs (through transportation distances), must be considered. In general, farms with higher beet yields and shorter transportation distances will find beet production more attractive than those with lower yields and higher distances. Site specific factors, including yields and transportation distances, production and opportunity costs, along with ethanol and feedstock prices, determine the production of energy beets in a region.

2.2 EMPIRICAL MODEL

Study Area

North Dakota is one of the northernmost states in the continental US. The majority of the state is in the Northern Great Plains of North America. It borders the Canadian provinces of Saskatchewan and Manitoba on the North, South Dakota on the South, Montana on the West and Minnesota on the East. The Eastern border of the state is defined by the Red River of the North. The Red River Valley contains fertile croplands and is a locus of sugar beet production in the US (Figure 1).

(Figure 1)

The most productive croplands are located in the Red River Valley in the East. The Southwestern portion of the state contains relatively fewer and less productive croplands and also generally receives less precipitation. As a result of the climate, in general, and the presence of sugar beet production in the Red River Valley, five sites in the East and North Central regions of the state were chosen as candidate sites for a bioethanol plant. More specifically, Cando, Carrington, Jamestown, Langdon and Valley City were chosen as they have sufficient labor, rail connections, distance from the Red River Valley and favorable growing climates for energy beet production. The proposed ethanol plant at each location could process 20,000,000 gallons of ethanol and consume 760,000 tons of beets.

North Dakota croplands were isolated from the land use layer and aggregated to 600m by 600m (~88.95 acre) parcels. Each of the relevant parcels was treated as a decision unit, resulting in 340,157 unique cropland units for analysis. Each cropland has site specific energy beet yields, transportation distances to plant sites and agricultural opportunity costs.

Economic Model

The empirical model proceeds as a two part profit maximization model. The decision to grow and transport energy beets for a static price is first considered for each of the 340,157 decision units. The beet profit optimization model, constrained by land and ethanol plant capacity, can be summarized as:

$$\max_{X_{ij}} \sum_{i=1}^{340,157} \sum_{j} \pi_{ij} X_{ij}$$

$$s.t. \sum_{j} X_{ij} \leq X_i^T, i = 1, \ldots, 340,157$$

$$and \sum_{i=1}^{342,688} \sum_{j=Beet} X_{ij} \leq 760,000$$

where X_{ij} is the area allocated to crop *j* on location *i* and X_i^T is the total area of land at location *i*. The producer at location *i* has two crop choices (*j*) energy beets in rotation, or a traditional rotation. Given plant capacity constraints, the sum of produced energy beets must not exceed the 760,000 ton capacity. The profit function is dependent upon prices, yields, variable and fixed harvest costs, opportunity costs, and transportation costs and distances.

The ethanol plant maximizes profit choosing between energy beet and molasses inputs. The optimization can be summarized as:

$$\max_{l} \pi^E(P^E, Q^E(l), VC(l), FC) \;\; s.t. K \leq 20{,}000$$

where l is the type of input used to produce ethanol and K is the capacity constraint for ethanol. There is also a constraint that the amount of energy beets used cannot exceed the amount created in the farm level optimization. In this way, the plant must offer a sufficient price to encourage energy beet production should it choose to use this input.

Model Specification

To estimate the empirical model, spatially explicit specifications are needed for: 1) energy beet yields; 2) energy beet production costs; 3) transportation costs; 4) agricultural opportunity costs; 5) ethanol production; and 6) energy beet and ethanol prices. This section outlines the base model specification. Sensitivity analysis examines the effects of changes in these parameters later in the paper.

Energy beet yields were estimated using a daily-stepping agronomic growth model that predicts harvested yields based on site specific daily temperatures, precipitation and solar irradiance, and soil conditions (De Laporte and Ripplinger 2016). Climate variables were obtained from NOAA (2016) and soil information was obtained from the USDA (2016). These kinds of growth models (Monteith 1977) apply the principles of the Beer-Lambert Law of light absorption (Monsi and Saeki 1955). Extensions of these models include evapotranspiration (Hargreaves and Allen 2003) and soil productivity. They have been utilized in a number of contexts and conditions for a number of different crops, including beets (Baey et al. 2014), and switchgrass and miscanthus (De Laporte et al. 2014; Jain et al. 2010; Khanna et al. 2008; Khanna et al. 2011). North Dakota average regional beet yields range from 6.7 tons/acre in the Southwest to 27.8 tons/acre in the South Red River Valley, while the state average is 15.3 tons/acre.

Energy beet production and transportation costs were obtained from North Dakota State University Extension Service materials. These costs are estimated at $565 per acre. Beet transportation costs using trucking are estimated at $0.31/ton/mile.

Agricultural opportunity costs are estimated using NDSU crop budgets from 2015. Opportunity costs are initially estimated for 7 regions determined by the NDSU Extension Service, based on common 4-year crop rotations. These costs are then scaled by the Crop Productivity Index obtained from USDA soil information. Energy beets are assumed to cost one-quarter of the potential net return of the rotation as opportunity costs, as beets are grown once every four years. The total net return of regionally specific 4-year rotations ranges from $71.97 in the Southwest to $136.63 in the South Red River Valley (Table 1).

(Table 1)

The ethanol plant in this study is based on Maung and Gustafson (2011). The plant has a capacity of 20,000,000 gallons per year. The base conversion efficiency of beets to ethanol is 26.4 gallons per ton. To reach capacity, the plant requires 760,000 tons of beets. The cost of beet-ethanol production is $0.34 per gallon. High cost beet molasses ($180/ton) can be used in the plant as a substitute for raw beets at a conversion efficiency of 79.2 gallons per ton.

The production of bioethanol is very dependent on prices. Beet feedstock prices could make up more than 75% of the costs of production. Current ethanol prices are around $1.50 per gallon. For the plant to make any positive net return, beet prices must be lower than approximately $30 per ton. The base model of analysis in this case considers an ethanol price of $1.50 per gallon at the factory gate and an offered beet price of $30 per ton delivered. The farmers in this model bear the costs of transportation.

3. RESULTS

To examine energy beet-bioethanol supply, this section presents the results of four modelling scenarios: 1) Base (P^B=$30/ton; P^E=$1.50/gal); 2) Capacity (P^B=$35/ton; P^E=$1.70/gal); 3) ¼ Transportation Costs (P^B=$30/ton; P^E=$1.50/gal); and 4) 1.5 Transportation Costs (P^B=$40/ton; P^E=$1.90/gal). In these scenarios, P^B is the price offered for energy beets and P^E is the price of ethanol. The results include the areas producing beets, both spatially and quantitatively, and the average distance, yield and return of these areas (Table 2).

The baseline scenario examines the possibility of bioethanol production using approximate current market conditions. The price of ethanol was set to $1.50/gal, which is similar to the current market price. The price of beets was set at $30/ton to approximately reflect the break-even feedstock cost of the plant with current ethanol prices. The results of the base model show that bioethanol production is only potentially feasible at the Valley City site (Table 2; Figure 2). The other four sites do not produce at, or anywhere close to, capacity. At Valley City, beets are transported from 1,020 sites (22,682 acres) an average distance of 15.7 miles to the plant. The average yield is 33.5 tons/ac from the selected sites and average returns are $26.09/ac. The beets are generally gathered from nearby sites and sites stretching to the east toward higher yields in the Red River Valley. In this scenario, the ethanol plant makes $436,049 in net revenue operating at capacity.

(Figure 2)

The capacity simulation examines the possibility of bioethanol production using market conditions that would encourage participation from each site. The price of beet feedstock was set at $35/ton to push production to the plant capacity. The price of ethanol was set to $1.70/gal to make the bioethanol plant at least break-even. The results show that bioethanol production at this level is potentially feasible at every site except Cando (Table 2; Figure 3). The other four sites produce at capacity, but Valley City ($67.97/ac) remains the best site, followed by Langdon ($33.24/ac), in terms of average net farm returns. Beets are transported from between 1,020 sites (22,682 acres) at Valley City and 1,349 sites (29,998 acres) at Jamestown. Average transportation distances range from 15.7 miles at Valley City to 19.4 miles at Langdon. Average yields range from 25.3 tons/ac at Jamestown to 33.5 tons/ac at Valley City. Spatially, a similar pattern exists to the base model, where beets are gathered from nearby sites and sites stretching to the east toward the Red River Valley. In this scenario, the ethanol plant net revenue is $648,170 operating at capacity.

(Figure 3)

The ¼ transportation costs scenario examines the effect of decreased transportation costs on the simulation. The prices of beet feedstock and ethanol are the same as in the base scenario. The decrease in transportation costs makes every site viable and significantly changes the pattern of cropland selection (Table 2; Figure 4). This scenario pushes beet production into the Red River Valley and nearby high yield sites. While Valley City remains the most profitable site, Jamestown becomes preferred to Langdon. The number of sites decreases across the board from the capacity scenario as the most productive lands are chosen. This causes average transportation distances to balloon from 15.7 to 36.7 miles in the case of Valley city. Similarly, average yields increase from 33.5 to 40.4 tons/ac and average farm returns increase from $26.09/ac to $88.94/ac. The highest yield sites in the Red River Valley end up shipping beets to all sites. In this scenario, the ethanol plant net revenue remains $436,049 operating at capacity.

(Figure 4)

The 1.5 times transportation costs scenario examines the effect of increased transportation costs on the simulation. To compensate for the increased transportation costs borne by the farmer, the price of beets had to be increased to $40/ton to create enough feedstock for each of the sites to produce at capacity. The price of ethanol was set to the price needed to make a profit ($1.90/gal). The increase in transportation costs significantly changes the pattern of cropland selection from the capacity scenario (Table 2; Figure 5). This scenario moves beet production to less distant croplands, as average transportation distances fall for each site compared to the capacity scenario. Valley City remains the most profitable site, as it has the highest nearby yields at an average of 31.2 tons/ac on selected croplands, but crop yields are lower than other scenarios. Consequently, cropland acres increase for every potential site. Langdon is still the second best site. In this scenario, the ethanol plant net revenue at capacity is $860,292.

(Figure 5)

4. DISCUSSION AND CONCLUSIONS

This paper examines the supply of energy beet-bioethanol from five potential plant sites in North Dakota and considers the effects of opportunity costs, supply chain logistics and carbon balances. The base scenario shows that Valley City is the only location that could successfully supply beet-bioethanol under current price conditions (Table 2; Figure 2). Increasing the price of beets to $35/ton would make beet production significantly more viable at Langdon, Carrington and Jamestown, but would necessitate higher ethanol prices (Figure 3). Decreasing transportation costs by a factor of four makes each site viable and completely changes the structure of the supply chain, where beets are shipped much longer distances from the highest yield beet sites in the Red River Valley (Figure 4). This could approximate intermediate beet piling and transport using rail, disaggregating plant siting from beet production. Increasing transportation costs by 50% brings production much closer to the plant, drops average yields and increases the amount of acreage needed to reach plant capacity (Figure 5).

While Valley City was selected as the most favored site in all scenarios (Table 2), it does have some drawbacks as well. The areas of the Red River Valley that are most attractive for beet production are the most profitable in the state and some do already produce sugar beets for food-grade sugar. One of the keys to beet-bioethanol in the state involves non-interference with the food-grade sugar industry and the associated US sugar policy. Therefore, if the most attractive sites in Valley City and Langdon, to a lesser degree, interfere with existing sugar beet production, the site likely becomes non-viable for political reasons.

Increasing opportunity costs would decrease the viability of beet-bioethanol, as these costs are relatively low in times of decreased crop prices. Supply chain logistics, including intermediate piling sites, could decrease transportation costs and make potential high yield sites in the valley more attractive. Ongoing life-cycle analysis shows that beet-ethanol is likely to reduce carbon emissions compared to conventional corn-ethanol. Should this be the case, price incentives in the RFS could make advanced beet-bioethanol production much more attractive. These scenarios constitute the next steps as this research moves forward.

Energy beet-based bioethanol in the state of North Dakota could be feasible under select conditions, even under current prices. However, ethanol prices seem to be at historic lows and investments in ethanol production capacity, especially considering the risk and uncertainty associated with the supply chain, would not be highly recommended. As the price of ethanol increases, this opportunity may become much more attractive.

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Table 1: Opportunity costs of North Dakota agriculture summarized by region.

Region	Rotation				Opportunity Cost ($/acre)
NW	Wheat	Lentils	Barley	Flax	$105.96
SW	Wheat	Corn	Wheat	Sunflower	$71.97
NC	Wheat	Sunflower	Barley	Flax	$120.87
SC	Wheat	Soybean	Corn	Sunflower	$90.68
EC	Corn	Soybean	Wheat	Soybean	$107.05
NE	Wheat	Soybean	Barley	Canola	$102.49
SE	Corn	Soybean	Wheat	Soybean	$134.28
NV	Corn	Soybean	Wheat	Drybeans	$133.37
SV	Corn	Soybean	Wheat	Soybean	$136.63

Table 2: Scenario results for the production of bioethanol in North Dakota showing decision units, beet quantity gown, average transported distance, average site yield and average farm return by potential plant location.

Location	Decision Units	Beets Grown (tons)	Average Distance (miles)	Average Beet Yield (tons/ac)	Average Farm Return ($/ac)
			Base (PB=30; PE=1.50)		
Cando	172	108,696	7.5	28.4	18.55
Carrington	111	80,924	22.2	32.8	10.89
Jamestown	19	11,391	7.1	27.0	8.17
Langdon	362	228,123	11.5	28.3	7.47
Valley City	1,020	760,000	15.7	33.5	26.09
			Capacity (PB=35; PE=1.70)		
Cando	983	564,218	15.2	25.8	18.60
Carrington	1,283	760,000	17.9	26.6	16.63
Jamestown	1,349	760,000	14.7	25.3	11.42
Langdon	1,149	760,000	19.4	29.7	33.24
Valley City	1,020	760,000	15.7	33.5	67.97
			1/4 Transportation Costs (PB=30; PE=1.50)		
Cando	950	760,000	66.2	36.0	38.22
Carrington	968	760,000	54.6	35.3	43.48
Jamestown	855	760,000	69.8	40.0	60.20
Langdon	942	760,000	40.8	36.3	58.60
Valley City	847	760,000	36.7	40.4	88.94
			1.5 Transportation Costs (PB=40; PE=1.90)		
Cando	1,412	760,000	13.7	24.2	29.52
Carrington	1,337	760,000	15.1	25.6	32.40
Jamestown	1,403	760,000	12.7	24.4	29.42
Langdon	1,288	760,000	13.2	26.5	46.73
Valley City	1,096	760,000	12.1	31.2	86.36

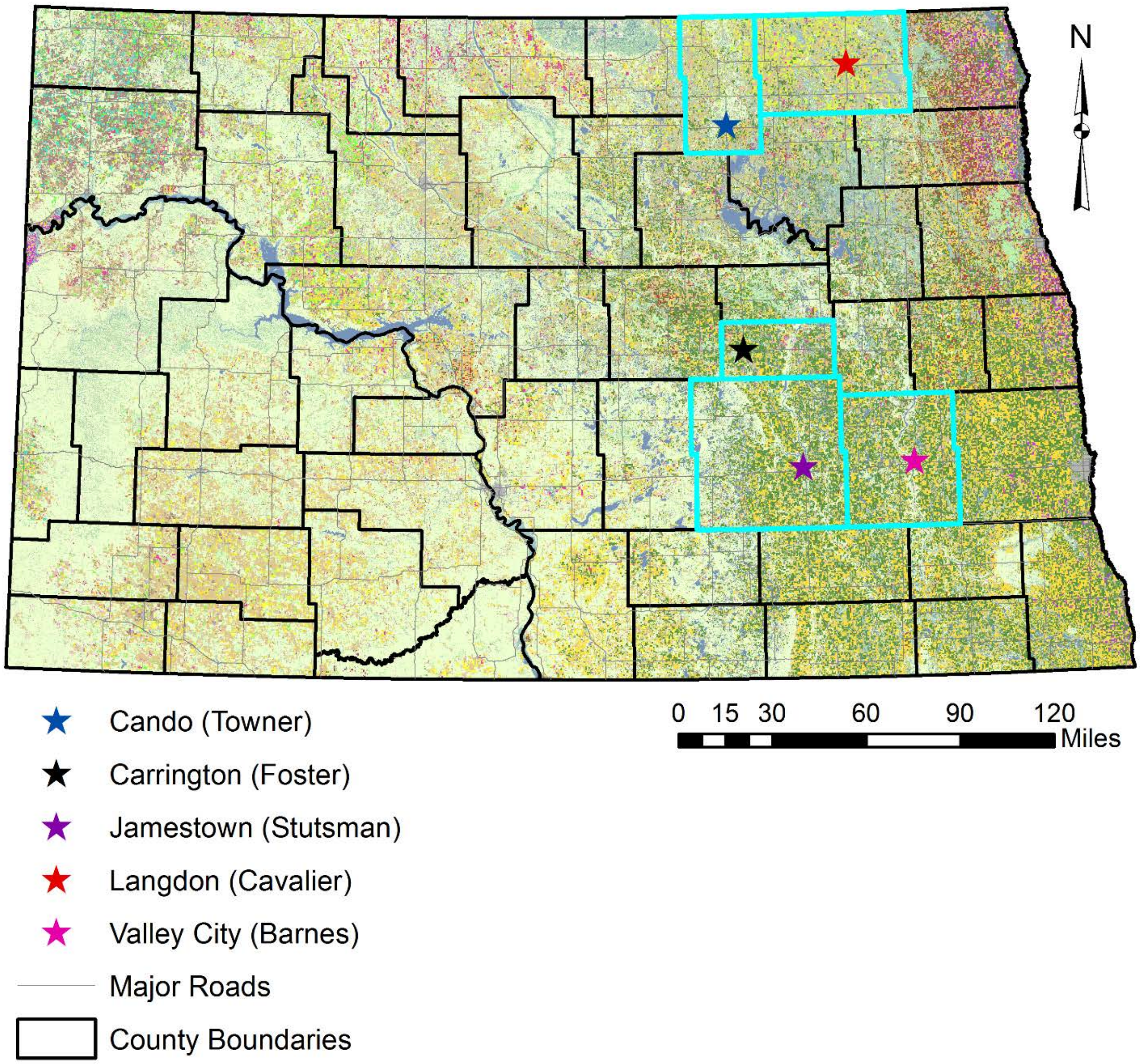

Figure 1: Land use in North Dakota highlighting agricultural lands, natural lands, developed areas and five potential bioethanol plant sites.

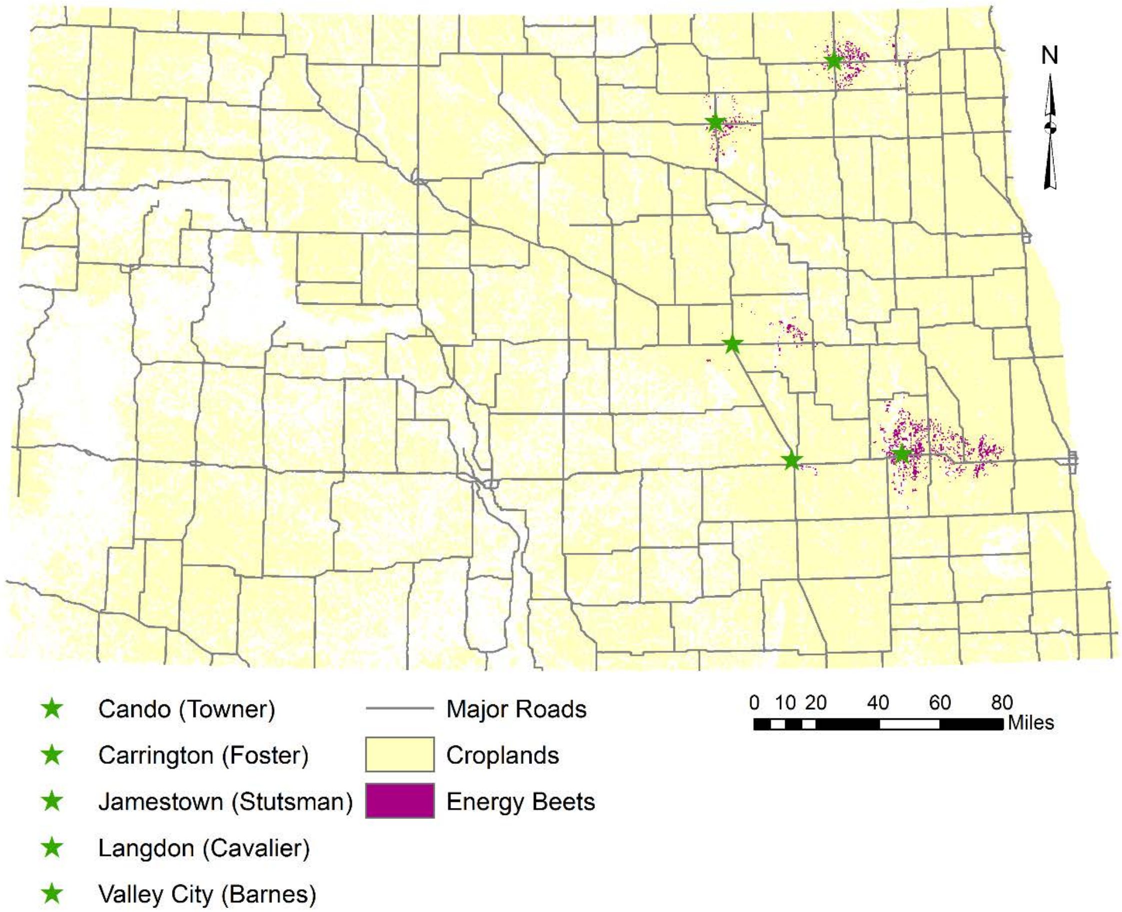

Figure 2: Croplands growing energy beets for selected North Dakota bioethanol sites in the Base Scenario (P^B=\$30/ton; P^E=\$1.50/gal)

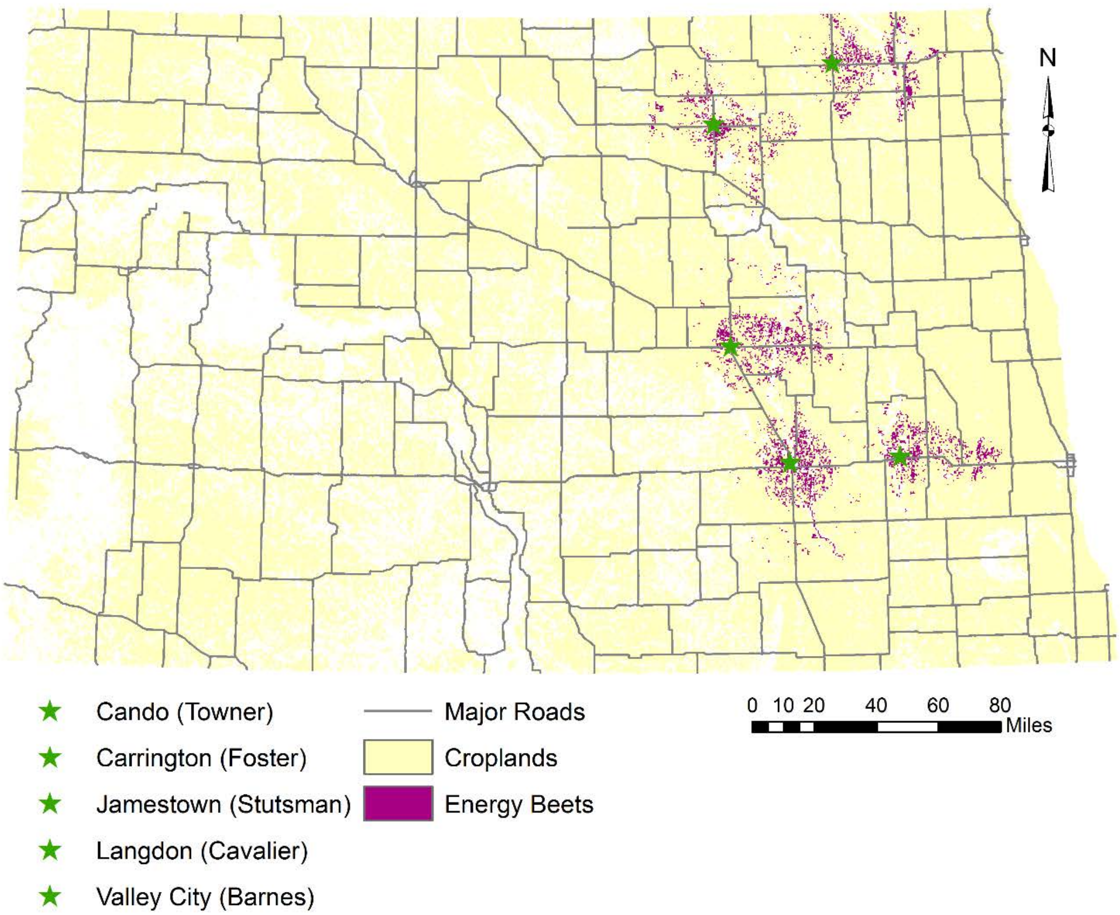

Figure 3: Croplands growing energy beets for selected North Dakota bioethanol sites in the Capacity Scenario (P^B=$35/ton; P^E=$1.70/gal)

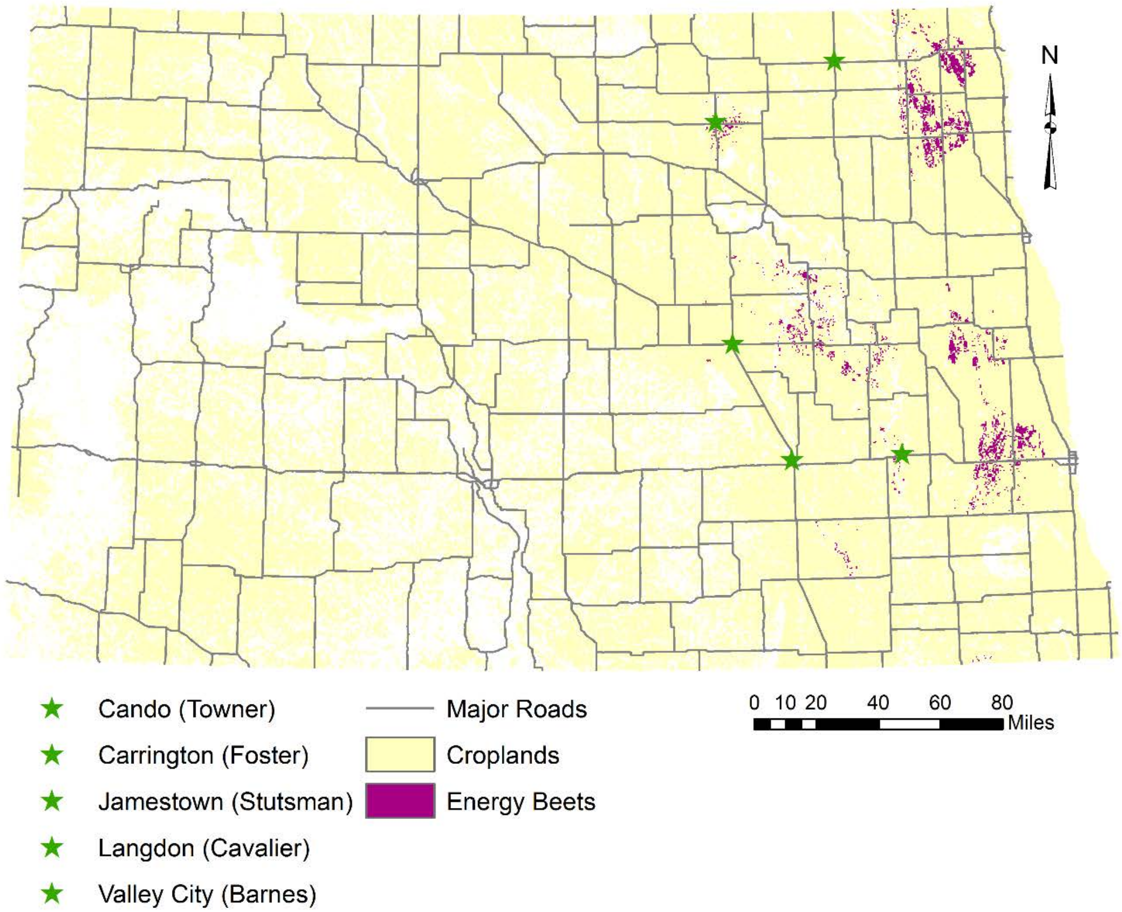

Figure 4: Croplands growing energy beets for selected North Dakota bioethanol sites in the ¼ Transportation Costs Scenario (P^B=\$30/ton; P^E=\$1.50/gal)

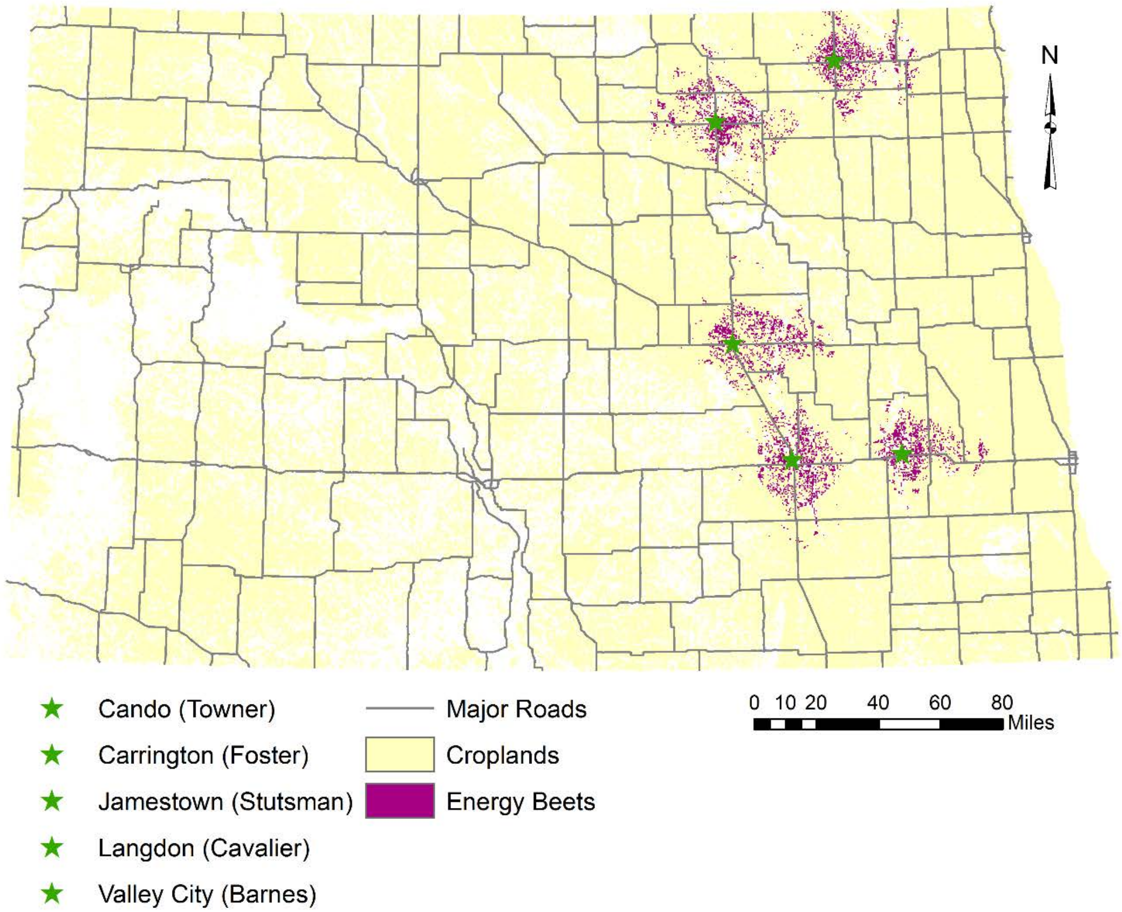

Figure 5: Croplands growing energy beets for selected North Dakota bioethanol sites in the 1.5 Transportation Costs Scenario (P^B=$40/ton; P^E=$1.90/gal)