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Effects of supply chain structure and biomass prices on bioenergy feedstock supply

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HIGHLIGHTS

- The supply of Ontario Switchgrass and Miscanthus is calculated to consider policy.
- 4 million tonnes transported locally attractive beginning at $69/t.
- 20 million tonnes exported with aggregation on-farm attractive starting at $198/t.
- 20 million tonnes exported with aggregation at ports attractive starting at $137/t.
- Local supply chains plausible with support, but export supply chains unlikely.

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ABSTRACT

This study assesses the supply of switchgrass and miscanthus, in Ontario, Canada, under different biomass prices and supply chain structures, using an integrated economic, biophysical and GIS model, to assess bioenergy policy. In a local, domestic supply chain, 4 million tonnes of baled biomass production per year becomes attractive for transport to the Nanticoke Generation Station at $69/t. For a larger scale export supply chain to Rotterdam in the form of biomass pellets aggregated on the farm, 20 million tonnes of production becomes attractive at approximately $198/t. For an export supply chain with aggregation at the major ports of Ontario, 20 million tonnes of baled biomass product is attractive for shipping to ports, with pellets subsequently transported to Rotterdam, at around $137/t. Higher bale transportation costs mean that agricultural lands closer to ports, but with lower yields, are preferred compared to the on-farm aggregation scenario. Given government incentives to ease the transition between annual and perennial crops and an actual realized demand from the Nanticoke Generation Station for biomass, this supply chain scenario is plausible. However, export scenarios are not attractive due to infrastructure constraints from current pellet processing capacity, and volatile international energy and commodity markets.

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1. Introduction

Well-functioning agricultural herbaceous biomass supply chains could help fulfill the increasing global desire for green energy by providing access to sufficient bioenergy feedstock. However, there are few examples of these supply chains at a large scale in North America. The government of Ontario, Canada, implemented the Green Energy Act, 2009, which provides incentives for green energy production, including biomass combustion, through feed-in tariffs, despite a likely insufficient supply of biomass [1]. Ontario domestic herbaceous biomass demand is limited to some home and greenhouse heating applications, but large-scale biomass combustion at the Nanticoke Generating Station, formerly the largest coal-fired plant in North America, is a possibility [2]. A greater demand for biomass may be provided through export to Europe or possibly the United States [3].

Wood pellets have a fairly well established, if limited, supply chain in Ontario. The Atikokan Generating Station consumes approximately 90,000 tonnes of woody biomass per year in a forested area. However, any additional large-scale demand for biomass likely exceeds current capacity. A supply of agricultural herbaceous biomass, likely in the form of perennial warm-season grasses, such as switchgrass or miscanthus, could evolve to fill this

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void. These grasses could be appropriate for large scale agricultural production due to their high biomass yields and soil carbon storage potential [4]. Theoretical biomass supply chains have been investigated qualitatively [5] and using game theory [6–8]. Difficulties with biomass supply chains, including storage issues, have been discussed [9,10]. The structure of any herbaceous biomass supply chain is highly dependent on the end-users of this biomass and their desired product. A large scale herbaceous biomass burner could require baled biomass with higher transportation, but lower production, costs, whereas a home heater in Europe could desire biomass pellets, with higher production, but lower transportation, costs.

The price provided to agricultural producers for herbaceous biomass is likely the most important factor in creating a supply of biomass, along with policy and a number of spatial factors, including the yields of biomass, the costs of production and the distances traveled to end-users. Wood pellets delivered to the port of Rotterdam, considered, due to its location in the Rhine Delta, the gateway to Europe, where home heating via pellet combustion is much more popular than in North America, were purchased for approximately 200 CAD/t in July of 2014 [11] according to limited publicly available information. According to an Austrian survey of wood pellet sellers, retail prices of loose pellets were approximately 319 CAD/t in July of 2016 [12]. Biomass pellet markets have not evolved to the level of their woody counterparts, but these price levels serve as a contextual basis for the analysis in this study. Agricultural opportunity costs also play an important role in the development of an agricultural biomass supply.

A number of large-scale biomass supply chain models with very specific detail have been developed [13–15]. However, the data inputs to these models are significant and Lam et al. [16] has discussed the advantages of model size reduction. Additional studies have discussed techno-economic assessments of biomass [17,18], economic potential in China [19] and cost-effective rural district heating [20]. Biomass processing, transportation and logistics have been considered using mathematical modeling techniques [21], such as linear programming [22], and integrating GIS [23,24], including facility siting [25]. However, a comparison of alternate supply chain structures, combined with processing and transportation considerations, has been scarcely examined. The least-cost size of pelletization and torrefaction depots, considering biomass moisture issues, has been examined [26]. Biomass torrefaction has also been compared to wind power [27]. However, the aforementioned studies refer to biofuel production, rather than electricity generation, or deal with woody biomass and crop residues, rather than dedicated energy crops.

Regarding dedicated agricultural biomass, switchgrass and miscanthus yields and break-even prices have been investigated in Illinois [28], the Midwestern US [29] and Ontario [30]. The supply of switchgrass and miscanthus has been investigated in Illinois [31]. However, the potential supply of switchgrass and miscanthus biomass under different biomass prices and supply chain structures is not known for Ontario. Therefore, the purpose of this study is to assess the supply of switchgrass and miscanthus in Ontario under different assumptions of biomass prices and supply chain structures, using an integrated economic, biophysical and Geographic Information Systems (GIS) model, to inform bioenergy policies. More specifically, this study reveals the price conditions and locations that could result in either switchgrass or miscanthus being produced for biomass combustion as bales at Nanticoke, or export as pellets to Rotterdam.

An integrated economic, biophysical and GIS approach is used to examine biomass supply under different supply chain structures in the province of Ontario. GIS is used to spatially connect economic and biophysical information to reveal detail that can be overlooked in other models. This model is less complex than some previous biomass supply chain models [13–15], but deals with both combustion and export, rather than bio-fuels, and examines the context of Ontario, Canada. This paper builds upon previous integrated models [28,29,31] by examining the Ontario context and using data at a much finer scale, moving from the county level, down to the field level (9 ha units) regarding biomass crop yields and costs. Due to the political nature of county boundaries, they do not always follow climate or other spatial patterns. Moving from the county level of analysis, closer to the individual, eliminates some of these issues and gives a clearer picture of areas more suitable for biomass production and their distances to points of interest. This also allows microeconomic decisions to be modeled by units more similar to distinct individuals, rather than by county level social planners, allowing a more nuanced analysis of the results. It also promotes considerations of precision agriculture and big data analysis that will move economic efficiency forward in the future.

An examination of biomass supply chain alternatives is followed by a description of the empirical model that includes the study area, an overview of the economic decision model and a description of the supply chain and price scenarios. The results of the integrated economic, biophysical and GIS model are then presented, followed by discussion and conclusions.

2. Method

2.1. Biomass supply chain

Currently, there are no agricultural herbaceous biomass supply chains operating in Ontario. However, examining similar supply chains, such as those from woody biomass, or hay and straw, can reveal the possible structure, or structures of these supply chains. A supply chain connects sellers and buyers together through space - it defines the process by which, in this case, agricultural biomass moves from the farm to the end-user. There could be many end-users of agricultural biomass, including ethanol plants, large or small-scale biomass burners, horse farms, and even chemical or bio-chemical industries. An examination of the end-users generally identifies two different types of products. The first is a more bulky baled product, for large-scale biomass combustion, ethanol production, or for animal bedding, likely shipped shorter distances. The second is an aggregated or densified product for small-scale combustion, or long distance travel including export. Aggregation, likely in the form of pelletization (cleaning, chopping, and grinding biomass into a molded pencil sized product), or torrefaction (the creation of biocoal through mild pyrolysis), could occur on farm, or at a specialized facility.

The supply chain for herbaceous biomass starts at the farm. If the value of biomass production exceeds the opportunity cost of traditional agriculture, a producer may decide to supply biomass. This decision would be dependent on site specific yields, prices from the buyer, and transportation, aggregation and opportunity costs. As biomass prices go up, the attractiveness of biomass production increases. Conversely, as harvest, transport, aggregation, or opportunity costs increase, biomass becomes a less attractive proposition to agricultural producers.

Assume a profit maximizing farm business has a biomass profit function:

$$\pi^B(P, X, Q(i), VHC, FHC, AC, OC, TC, L(i)) \quad (1)$$

where π^B is the net profit from biomass production, P is the price of biomass per unit, X is the area of biomass produced, i is the site specific location of biomass production, $Q(i)$ is the yield per area at location i, VHC is the variable harvest cost per unit, FHC is the fixed harvest cost, AC is the aggregation cost per unit, OC is the

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