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Potential and impacts of renewable energy production from agricultural biomass in Canada

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HIGHLIGHTS

- This study quantifies the bioenergy production potential in the Canadian agricultural sector.
- Two presented scenarios included the mix of market and non-market policy targets and the market-only drivers.
- The scenario that used mix of market and policy drivers had the largest impact on the production of bioenergy.
- The production of biomass-based ethanol and electricity could cause moderate land use changes up to 0.32 Mha.
- Overall, agricultural sector has a considerable potential to generate renewable energy from biomass.

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ABSTRACT

Agriculture has the potential to supply considerable amounts of biomass for renewable energy production from dedicated energy crops as well as from crop residues of existing production. Bioenergy production can contribute to the reduction of greenhouse gas (GHG) emissions by using ethanol and biodiesel to displace petroleum-based fuels and through direct burning of biomass to offset coal use for generating electricity. We used the Canadian Economic and Emissions Model for Agriculture to estimate the potential for renewable energy production from biomass, the impacts on agricultural production, land use change and greenhouse gas emissions. We explored two scenarios: the first considers a combination of market incentives and policy mandates (crude oil price of \$120 bbl^{-1}; carbon offset price of \$50 Mg^{-1} CO_2 equivalent and policy targets of a substitution of 20% of gasoline by biomass-based ethanol; 8% of petroleum diesel by biodiesel and 20% of coal-based electricity by direct biomass combustion), and a second scenario considers only carbon offset market incentives priced at \$50 Mg^{-1} CO_2 equivalent. The results show that under the combination of market incentives and policy mandates scenario, the production of biomass-based ethanol and electricity increases considerably and could potentially cause substantial changes in land use practices. Overall, agriculture has considerable potential to generate biomass for energy and a significant potential for GHG emission reductions, however the proportional mix of policy and market incentives would have a large impact on the type of bioenergy produced.

1. Introduction

Biomass is one of the major sources of energy that is estimated to contribute between 10% and 14% of the world's energy supply [1–3]. Over the past several years, several countries have established policy targets to increase their production of renewable energy from biomass [4–6]. For example, the European Union plans to increase the share of liquid biofuels to 10% of total gasoline consumption by 2020; the policy targets in the U.S. aim to produce 136 billion liters of biofuel by 2022 and China has set a target of using 10% ethanol in total gasoline consumption by 2020 [7–10]. Canada has implemented biofuel targets of 5% renewable content in gasoline as of 2010 and 2% renewable content in diesel fuel

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and heating oil as of 2011 [11]. To date in Canada, almost all renewable bioenergy from agricultural feedstocks has come from grains and oilseeds in the form of first-generation biofuels [12,13]. However, a significant research program is underway to enable the use of cellulosic biomass from crop residues and dedicated energy crops and further expand the biomass supply for renewable energy production [14–17].

Renewable energy production has the potential to help reduce greenhouse gas (GHG) emissions by displacing the use of fossil fuels [18–20]. Based on previous analysis undertaken by Agriculture and Agri-Food Canada (AAFC) [21], the largest potential for agriculture to contribute to reduced GHG emissions is to provide feedstocks for bioenergy that could offset GHG emissions from fossil fuels. However, wide adoption of biomass production for energy may have unintended impacts on land use practices and land conversion dynamics which could further increase GHG emissions from agriculture [22–24]. Furthermore, the production of biomass may increase competition for available land, impact agricultural crop production and have impacts on the prices and availability of agricultural commodities [25,26].

Since bioenergy production has the potential to reduce GHG emissions, its production is a likely target for incentives that can recognize this, such as a price on carbon use. Governments have also used mandates to encourage biofuel production [27,28].

There is a great deal of literature focused on biomass production from agriculture, with one of the main research areas being the assessment of the impacts of mandatory bioenergy targets on agriculture and land use change using partial or general equilibrium models [29–33]. Similarly, considerable research has been conducted on studying potential biomass energy supplies [34–36]. However, few studies have focused on comparing the impact of market versus policy drivers on biomass and bioenergy supply, land use change and greenhouse gas emissions.

In this paper, we present the results of two forward-looking scenarios for the Canadian agricultural sector over the near-future period to 2017; scenarios which examine the future impacts of using a combination of market incentives and policy mandates aimed at increasing the production of energy from biomass in the agricultural sector. The first, "markets and mandates" scenario looks at the implications of a suite of policy mandates and market incentives aimed at increasing bioenergy production in the agricultural sector, and it is compared with a second scenario which uses only market-based carbon sequestration incentives.

2. Methodology

2.1. Canadian Economic and Emissions Model for Agriculture (CEEMA)

We used the Canadian Economic and Emission Model for Agriculture (CEEMA) to estimate the impact of policy scenarios on resource utilization, GHG emissions and bioenergy production in the Canadian agricultural sector. CEEMA is composed of two models – the Canadian Regional Agriculture Model (CRAM), which assesses resource use implications on a regional scale [37–39], and the Greenhouse Gas Emissions Module (GHGEM), which assesses the GHG emissions associated with changes in resource use in the agricultural sector (Fig. 1) [40]. For this study, the CRAM component of CEEMA was enhanced to be able to potentially expand the agricultural land base through deforestation on private lands. We acknowledge that the location and extent of deforestation in actual practice would likely be limited by environmental constraints, sustainability considerations and decision-making perceptions among landowners, but the intent was to evaluate the potential impacts, risks and pressures associated with clearing land for agricultural production. The estimates of land conversion

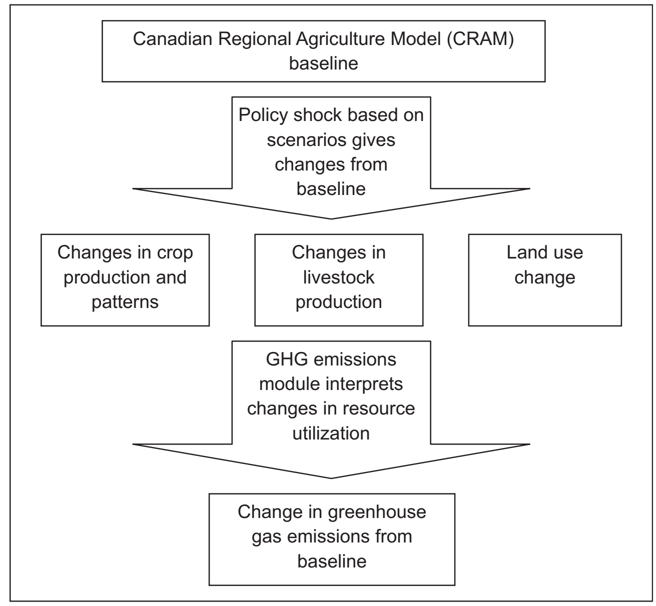

Fig. 1. General structure of the Canadian Economic and Emissions Model for Agriculture (CEEMA).

from non-agricultural to agricultural use were based on regional assessments of forested land that has agricultural potential. This information was obtained through a geographical intersection of soil capability [41] and land cover maps [42], with the elimination of any areas identified as "protected" for environmental conservation. Land ownership was not considered in the analysis.

2.1.1. The canadian regional agriculture model

We used the Canadian Regional Agriculture Model (CRAM) to assess the economic impacts and resource utilization patterns resulting from the bioenergy scenarios. CRAM is an agricultural sector static partial equilibrium non-linear optimization model that maximizes a modified welfare function (consumer plus producer surplus minus processing and transportation costs) subject to a set of linear constraints describing various aspects of the Canadian agricultural sector. The model allows for both interprovincial and international trade in primary and processed agricultural products. The model also incorporates Government policies through direct payments (or subsidies) and indirectly through the adjustment of supply, management, input and transportation costs [37–40]. While CRAM does not provide information on the growth of the agricultural sector over time, it can generate a very detailed snapshot of the agriculture sector before and after a range of price and policy interventions.

CRAM incorporates all primary production for both crops and livestock, and also includes some processing activities such as oilseed crushing and production of biofuels from grains and oilseeds. The model includes three major sets of sub-matrices that deal with crop, forage and livestock production and processing, trade and transportation activities and domestic sales and exports. The domestic sales determine the level of agricultural commodity demand and prices for crop and livestock products. These prices and quantities are then used to calculate the consumer and producer surplus which is then added to the objective function. The model also includes three major groups of equations: resource constraint equations (which control land availability and livestock estimates), balance equations (which control the supply utilization for each commodity type) and ratio equations (that allocate demand to the provincial level).