Macroeconomic Effects of Second-Generation Biofuel Sector in Canada

by

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Abstract

The Government of Canada has committed to reducing Canada's overall greenhouse gas (GHG) emissions to 511 Mt CO2 eq by 2030. Considering the GHG reduction target, energy and food security, the focus on second-generation biofuel is significant. Some countries have issued mandates to stimulate advanced biofuel industries, thus increasing the production of second-generation biofuels. However, it is unclear how this kind of mandate will influence the economy of Canada. With this backdrop, an input-output (IO) model was developed to estimate the macroeconomic impact of introducing a new second-generation biofuel industry into Canada. A modified "biproportional" matrix balancing technique (RAS method) is applied to reconcile the model and dynamically simulate the trajectory over the change. Results show that the agriculture sector benefits from the new sectors overall while animal production and its downstream sectors experience a slight decrease. Manufacturing and mining sectors show a significant impact. The further expansion of the production and consumption of second-generation ethanol also contributes significantly to GHG reduction. It is concluded that the development of a second-generation biofuel sector will lead to economic, social, and environmental benefits.

Résumé

Le Gouvernement Canadien a promit de réduire les émissions globales de Gaz à Effet de Serre du Canada à équivalent de 511 Mt CO2 d'ici 2030. Compte tenu des buts de réduction des émissions de gaz à effet de serre, de la sécurité énergétique et alimentaire, l'accent mis sur les biocarburants de deuxième génération est remarquable. Certains pays ont émis des arrêtés pour stimuler le secteur de biocarburant de pointe, afin d'augmenter la production de biocarburant de deuxième génération. Cependant, on ne peut pas savoir que comment ces arrêtés affecteront l'économie du Canada. Avec ce contexte, nous avons développé un modèle d'entrée-sortie afin d'estimer les impacts macroéconomiques de l'introduction du nouveau secteur de biocarburant de deuxième génération au Canada. Une méthode RAS modifiée est appliquée pour accorder le modèle et simuler dynamiquement la trajectoire de changement. Les résultats ont montré que l'expansion du secteur agricole a bénéficié du nouveau secteur, tandis que la production animale et ses secteurs en aval ont significativement diminué. Le secteur manufacturier et minier ont présenté une influence significative dans ce processus. On conclut que le développement du secteur de deuxième génération apportera des bénéfices économiques et sociaux en futur.

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Chapter 1: Introduction

There is growing interests in biofuels around the world because they are improving biomass use while addressing energy costs, energy security and global warming concerns caused by petroleum fuels. The United States (54 percent) and Brazil (30 percent) are the worldwide leaders in fuel ethanol production, accounting for 84 percent of global supply (Renewable Fuels Association 2020). The Canadian fuel ethanol sector is in its infancy and its fuel ethanol production only accounts for 2 percent of the world's production.

In Canada, the renewable fuel in gasoline and diesel pools has grown since 2010. Between 2010 and 2017, annual fuel ethanol use grew from approximately 1.70 billion liters to 3.05 billion liters (Wolinetz et al. 2019). In 2017, ethanol fuel accounted for 6.2 percent of the gasoline pools (Bradford 2019). It should be noted, however, that current operational ethanol plants from second-generation feedstock in Canada only have the capacity of 11 million liters (Ethanol Producer Magazine, 2021), only 0.36 percent of total ethanol use. Over the same period, annual biodiesel consumption rose from approximately 0.12 billion liters to 0.38 billion liters. Also, hydrogenation-derived renewable diesel (HDRD) was added into diesel in the amount comparable to biodiesel recently, increasing from 0.037 billion liters to 0.33 billion liters. Annual greenhouse gas (GHG) reductions due to renewable fuel use rose from 2.1 Mt to 5.5 Mt, totally 34.3 Mt CO_2eq. Since 2013, fuel ethanol has contributed more than 6 percent of the gasoline pool volume, while biodiesel and HDRD together have accounted for about 2 percent in the diesel pool volume (Wolinetz et al. 2019).

However, current domestic biofuel production is not enough to meet existing biofuel mandates, therefore the domestic gap between supply and demand widens (Mukhopadhyay et al. 2017). To satisfy the demand driven by the biofuel mandate, imports are only a temporary solution to this imbalance, whereas domestic biofuel expansion might be the best long-term strategy. Indeed, Canada has the potential for producing more domestic biofuels than those currently mandated by existing regulations and initiatives. Liquid biofuels in Canada are being developed using a wide variety of feedstocks, technologies, and applications at various stages (Lubieniechi and Smyth 2016).

In addition, countries are further committed to working towards for a more environmentally sustainable world since the meeting in Paris at COP21 in 2015. These countries are making an effort to develop policies that will lead to a low-carbon economy (UNCTAD 2015). Canada pledged to decrease its GHG emissions by 30 percent below 2005 levels (730 Mt CO_2eq) by 2030 under the Paris Agreement (ECCC 2020a). To achieve this goal, government and researchers have investigated the carbon intensity of available biofuels and suggest that biofuel production is less emissions intensive than gasoline (Wolinetz et al. 2019). The Renewable Fuel Standard (RFS) and the Energy Independence and Security Act of 2007 (EISA) classified biofuels as conventional, advanced, or cellulosic based for their capacity to decrease GHG emissions by 20 percent, 50 percent, and 60 percent, respectively (Maung et al. 2013).

Conventional first-generation biofuel is already well-commercialized and dominate global biofuel market with mature technologies. However, biofuel production accounts for an increasingly significant proportion of global cereal, sugar, and vegetable oil use over the past decade (OECD/FAO 2011; 2021). Between 2018 and 2020, 15.80 percent of corn and 22.63 percent of sugarcane was estimated to be supplied as a feedstock to the global bioethanol refining sector on average, while around 14.93 percent of vegetable oil was used for global biodiesel production (OECD/FAO 2021). The considerable share leads to the fuel versus food debate. Also, current Canadian ethanol production is mainly from feedstocks such as grain, which may negatively impact food supply and not substantially meet the GHG reduction goal (Campbell et al. 2018). Other limitations, such as inefficient energy use and utilization of arable lands should also be taken into consideration (Eisentraut 2010; Gasparatos et al. 2013; Lee and Lavoie 2013; Larson 2008).

First-generation biofuel is criticized for not significantly reducing GHG emissions (De Lucia 2011). During production, corn and wheat are two of the largest GHG emitters among agricultural crops produced in Canada (Dyer et al. 2010). But they are the most often used biofuel feedstocks (Li et al. 2012b; Scaife et al. 2015). Scaife et al. (2015) also point out that crop cultivation causes a carbon footprint, which is sourced from soil organic carbon. The carbon release potentially negates the GHG reduction from biofuel and there is a question of the sustainability of current biofuels policy (Edwards et al. 2008; Laborde and Valin 2012). For example, the U.S. renewable fuel standard (RFS2) resulted in little change on global GHG reduction, while higher blending rate or larger proportion of conventional ethanol in the mandate might even raise global GHG emissions (Mosnier et al. 2013). Another study also indicated that conventional biofuel contributes to a reduction in GHG emissions but might be insufficient to meet GHG reduction targets in the EU (De Lucia and Bartlett 2014). Nevertheless, growing production of Canadian biofuel is heavily dependent on government policies based on the assumption that these biofuels help accomplish national climate change goals by lowing carbon emissions. Limited GHG reduction from first-generation biofuel have been assessed by life cycle analysis, which has resulted in a growing interest in second-generation biofuels, especially cellulosic ethanol.

Second, first-generation biofuel competes with arable land since their feedstocks are crops (Banse et al. 2011; Birur et al. 2008; Burrell et al. 2012; Du Lucia and Bartlett 2014; Fonseca et al. 2010; Hertel et al. 2010; Keeney and Hertel 2009; Taheripour et al. 2012). Approximately 70 percent of the global bioenergy is derived from conventional feedstock, raising concerns about land and water scarcity for food and fiber cultivation (Eisentraut 2010; Gasparatos et al. 2013; Ho et al. 2014). The agriculture sector must make the necessary adjustments when certain cropland is used for feedstock production instead of food cultivation to meet the demand for first-generation biofuel (De Lucia and Bartlett 2014; Weng et al. 2019). The land use change (LUC) caused by first-generation biofuel production is the basis for the food-versus-fuel debate. First-generation feedstock utilizes approximately 2-3 percent of the global land (and water) for agriculture, enough to provide food for 30 percent of the malnourished people (Rulli et al. 2016). Moreover, the intense competition for land and crops raises food prices and further threatens food security (Ho et al. 2014; Tomei and Helliwell 2016). On the other hand, considerable land redistribution also involves significant reduction in forests and pastures (Bouët et al. 2010; Laborde and Valin 2012; Malins 2013; Timilsina et al. 2012). For example, Filho and Horridge (2014) suggests that each additional hectare of sugarcane for biofuel take away 0.14 hectare of new land, as well as 0.47 hectare grazing pasture in Brazil. The conversion of land has the potential to significantly increase GHG emission (IPCC 2006; 2020).

Third, first-generation biofuels also raise other concern about environmental sustainability (e.g., water table and soil acidification). More biofuel refineries may decrease water supply to food manufacturing and put further strain on water resources in countries where water shortage is a growing concern, such as India (Cherubini and Jungmeier 2010; OECD/FAO 2011). The expansion of first-generation biofuel might also cause a reduction in water and soil quality because of the use of fertilizer and agrochemical inputs, particularly Brazilian sugarcane-based bioethanol refining as well as palm-oil-based biodiesel production in Southeast Asia (Cherubini and Jungmeier 2010; Gasparatos et al. 2013). In addition, corn ethanol and biodiesel have lower energy returns on investment than corresponding fossil fuel (Baral and Bakshi 2009; 2010). Another example is cassava-based ethanol. Its energy ratio is about 0.70 MJ/MJ, implying each megajoule of cassava-based ethanol output consumes up to 7 megajoule during the production process (Yu and Tao 2009b).

The cumulative environmental consequence of first-generation biofuel refining has sparked interests in lignocellulosic feedstock, such as agricultural and forest residues, which are less costly and readily accessible (Ho et al. 2014). Second-generation biofuels based on lignocellulosic biomass have significant environmental and energy gain in comparison to most first-generation biofuels (Mohr and Raman 2013; UNCTAD 2015). It is noteworthy that the second-generation class performs better when their feedstocks are not dedicated plantations cultivated on agricultural land (Havlik et al. 2011).

Second-generation biofuel plays a greater role in developing a low-carbon economy compared to first-generation biofuel. GHG reductions from second-generation biofuel are higher than first-generation biofuel as well as gasoline and diesel (Baral and Bakshi 2010; Bowyer et al. 2018; Zaimes et al. 2017; Zhao et al. 2016). According to life cycle assessment, conventional biofuel achieves 40-80 percent lower GHG emissions than corresponding fossil fuel, whereas second-generation biofuel can lead to almost 100 percent less GHG emissions compared to conventional fuel (Natural Resources Canada 2016). For example, when replacing a high-input annual crop with a low-input perennial crop that can be used as a biofuel feedstock, the central US might move from a net source to a net sink for GHG emissions (Davis et al. 2012). Similarly, Australian lignocellulosic biofuel industry from forestry biomass was estimated to be a net carbon sequester (Malik et al. 2016). A study by Foteinis et al. (2020) further showed that total carbon per ton of second-generation biodiesel refining might be 0.55t CO_2eq, around 40 percent less than conventional biodiesel.

In addition, second-generation biofuel has relatively small effects on land use, especially in developed countries. To be specific, agricultural residues may not lead to additional land use change (Schnepf 2010) and it may further reduce emissions if residue burnt in the field is used (IPCC 2006; 2020). Biofuel from energy crops can alleviate land use to a certain extent. Cellulosic ethanol refining from hybrid poplar required less wheat and oilseed land in comparison with conventional ethanol production in Canada (Campbell 2018). Similarly, a case study of China indicated that if marginal land was used for feedstock cultivation, intensive farmland competition caused by ethanol refining could be eased (Weng et al. 2019). When cellulosic biofuels accounted for around half of the biofuels in the US, only approximately 2 percent more total cropland could support 80 percent more biofuel to satisfy its mandate (183 billion liters) in Brazil and the US in 2022 (Nuñez et al. 2013). Moreover, GHG emission reductions from second-generation biofuel from switchgrass and miscanthus might be still large even after considering emissions caused by indirect land-use change (Davis et al. 2012). According to Havlik et al. (2011), second-generation biofuel supply derived from sustainably managed existing forests would result in a negative indirect land use change (ILUC) factor, implying that it would reduce total GHG emissions by 27% in comparison with traditional fuels by 2030. However, the ILUC factor for global first-generation biofuel production was generally positive, meaning GHG emission reduction in biofuel use needed 25 years to repay.

Furthermore, second-generation biofuels can replace more traditional fuels in the gasoline pool compared to first-generation biofuel in general (Bowyer et al. 2018; Swana et al. 2011). Energy gain of cellulosic ethanol was estimated to be considerably larger (15.9 MJ/L) compared to corn-derived biofuel (0.4 MJ/L) using life cycle assessment (Bansal et al. 2016; Swana et al. 2011). In addition, the efficacy of second-generation biofuel might be better than first-generation biofuel. An early study showed that the energy return on investment (EROI) ratio of second-generation ethanol production could be 4.4-6.6 (Sims et al. 2008). The EROI for cellulosic biofuel refining from forestry feedstock was estimated to be 2.7-5.2 (Malik et al. 2016). Another recent study of Zaimes et al. (2017) demonstrated that the EROI from second-generation biofuel lied between 1.32 and 3.76, higher than the estimate for corn-derived ethanol (1.3).

On the other hand, third-generation biofuels are still not competitive with second-generation biofuels. In fact, third-generation biofuels have the potential to overcome shortcomings of both first- and second-generation biofuels and are more likely to include other desired biofuels like biodiesel (Scaife et al. 2015). Third generation biofuels (e.g., microalgae and cyanobacteria-based) provide enhanced production and the ability to extract nutrients from the waste streams (Scaife et al. 2015). For example, algae produces much more energy per unit surface area than plants presently utilized to produce biofuels (Bowyer et al. 2018). However, there remain geographical and technical challenges (Lee and Lavoie 2013). The overall carbon footprint per unit of second-generation biodiesel may be an order of magnitude less compared to third-generation biodiesel (microalgae-based) due to the immature third-generation technology (Foteinis et al. 2020). Also, third-generation biofuel technology might restrict scalability to maintain better productive and sustainable production (Scaife et al. 2015). As a result, algae-based biofuels may not gain a competitive advantage over the emerging cellulosic biofuel industry at least in the medium term (Bowyer et al. 2018).

Lignocellulosic biomass has been used to generate second-generation biofuel since they are commercially feasible and have significant environmental benefits, notably substantial GHG reduction (Shabani and Sowlati 2013). A few examples of second-generation biofuels are bioethanol, biodiesel, methanol, Fischer-Tropsch Diesel, Dimethyl ether, aviation fuel, bio-hydrogen, etc. (Demirbas 2007; Güell et al. 2013; Sikarwar et al. 2017). Second-generation bioethanol, especially cellulosic bioethanol, is the first choice in most countries considering available feedstocks and complexity of conversion (Gerbens-Leenes et al. 2009; Scaife et al. 2015; Schmer et al. 2008). In Canada, bioethanol derived from lignocellulosic biomass is more appealing, given that Canada is rich in available feedstocks, enough to increase bioethanol by 13 billion liters annually, as well as marginal lands for potential energy crop cultivation (Scaife et al. 2015). Therefore, the thesis mainly focuses on lignocellulosic biomass for second-generation ethanol in Canada.

Recently there has been some major advances in core technologies (Ho et al. 2014; Wang et al. 2020a). Several commercial-scale refineries have operated since 2014 with relatively modest output worldwide (Bowyer et al. 2018). The significant cellulosic bioethanol plants around the world that have been built or planned are shown in Appendix A. The level of development and potential in North American shows considerable opportunities for their application in Canada. The major Canadian cellulosic bioethanol plants are listed in Appendix B. The large-scale commercialization of second-generation ethanol has not yet occurred in Canada (Littlejohns et al. 2018; $(S\&T)^2$ Consultants Inc. 2018; Scaife et al. 2015; Wang et al. 2020a).

Certain technology challenges still exist for second-generation biofuels (Ho et al. 2014; van der Meij 2017; Merritt 2017) and thus further commercialization may be difficult and slow (Campbell et al. 2018). Major impediments involve substantial capital investment, accounting for around 35–50 percent of total cost, as well as operational and regulatory uncertainties (Campbell et al. 2018; Carriquiry et al. 2011; Lubieniechi and Smyth 2016; Scaife et al. 2015; $(S\&T)^2$ Consultants Inc. 2018; Yue et al. 2014).

Biofuel policies are critical for the development of the biofuel industry, especially lignocellulosic ethanol production (De Lucia and Bartlett 2014; Hélaine et al. 2013). With unclear policy signals and considerable regulatory uncertainty, cellulosic biofuel pioneers might choose to leave the industry. Therefore, it is crucial for governments to provide a consistent biofuel policy mix. Several countries have implemented biofuel policies that require and support cellulosic bioethanol production to achieve the economic and environmental gains, including the U.S., Brazil, Canada, China, and the E.U. In the US, legislation has been enacted at the federal level to stimulate second-generation bioethanol production and restrict corn-starch-derived bioethanol refining (Schnepf and Yacobucci 2013). The expanded Renewable Fuel Standard (RFS2) mandates 36 billion gallons of renewable fuel by 2022, of which 15 billion gallons (41.67 percent) should be conventional ethanol and 21 billion gallons would be advanced biofuel. More importantly, 16 billion gallons (44.44 percent) of the renewable fuel should be derived from lignocellulosic biomass (Carriquiry et al. 2011; EPA 2020).

The Canadian biofuel industry also relies highly on government policies (Hope et al. 2020). Canada has implemented policies that moderately support the domestic biofuel sector, with provincial governments mainly taking the lead (Scaife et al. 2015). Table 1.1 summarizes current provincial and federal policies. The federal Renewable Fuels Regulation came into effect in 2010 and requires a minimum blending rate of renewable content, mandating 5 percent renewable fuel in gasoline and 2 percent in diesel fuel and heating distillate oil. This drives the demand for ethanol (2.1 billion liters) and biodiesel (0.6 billion liters) each year, resulting in GHG savings of 4 million tones (Mukhopadhyay et al. 2017).

Canada further mandates average lifecycle carbon intensity (CI) in addition to specified proportion of renewable fuel in fuel pools. The federal government of Canada designed a regulation called the Clean Fuel Standard (CFS) highlighting fuel CI, following the British Columbian Renewable and Low Carbon Fuel Requirement Regulation (RLCFRR) as well as the California Low Carbon Fuel Standard. The CFS will mandate a decrease in the life-cycle CI of transportation fuels, with all liquid fuels in 2030 emitting 10 g CO_2eq/MJ less than the 2016 benchmark on average (ECCC 2018b).

Carbon pricing policies also bolsters advanced biofuels. Canadian carbon pricing backstop is designed for provinces without their own carbon pricing system, such as Ontario, Saskatchewan, Manitoba, and New Brunswick. Newfoundland, PEI and Nova Scotia are establishing provincial carbon pricing systems instead of following the federal system. The federal carbon pricing backstop have been in effect since April 1st, 2019. The carbon price will increase from $20/tonne in 2019 to $50/tonne by 2022 with annual increases of $10 (Government of Canada 2019). Like Alberta's carbon levy, the federal carbon price is exempt when the blending rate is higher than 10 percent in gasoline pool or 5 percent in the diesel pool (McKenna and Morneau 2018; Wolinetz et al. 2019).

Government policies have also provided incentives for R&D efforts and investments in the second-generation industry. The 2007 Budget allocated $500 million to Sustainable Development Technology Canada (SDTC) (Natural Resources Canada 2016). SDTC made loans to the private sector to transition demonstration-scale plants to commercialized plants for next-generation biofuels (Scaife et al. 2015; Mupondwa et al. 2017). In addition, research networks were funded by government concentrated on technologies for economic and sustainable ethanol production from lignocellulosic biomass (Mupondwa et al. 2017). The main research networks were connected by the Cellulosic Biofuel Network (CBN) as well as the Strategic Network in the Bioconversion of Lignocellulose to Ethanol (Scaife et al. 2015).

With government support and a wide range of potential feedstocks, further expansion of advanced biofuel production can be expected in Canada in the near future. The Canadian second-generation biofuel industry should have an extensive and promising future. Considerable advances in this industry might have the potential to

Table 1.1 Summary of Federal and Provincial Biofuel Policies Target in Canada

Location	Renewable content		average CI	carbon price	CO2 reduction
	Gasoline	Diesel			
Alberta	5%	2%	renewable content with 25% less carbon intensive than corresponding conventional fuel	\$30/t CO_2eq	-
Ontario	5% 10% since 2020 15% since 2025	4% renewable content with 70% reduction in CI relative to diesel fuel	10% reduction in CI by 2020 relative to a 2010 baseline	\$20/ t CO_2eq	-
British Columbia	5%	4%	20% of average CI reduction by 2030 compared to a 2010 baseline	\$40/t CO_2eq	25.4 Mt CO_2eq by 2030 (39.94% below 2005 level)
Federal government	5%	2%	CI target for all liquid fuels in 2030 will be 10 g CO_2e/MJ lower than a 2016 benchmark.	\$20/ t CO_2eq	219 Mt CO_2eq by 2030 (30% below 2005 level)

Source: Government of Canada 2019; ECCC 2018b; Wolinetz et al. 2019 transition Canada to a low-carbon economy and attain the GHG reduction goal with the collaboration of government, industry, and academia (Littlejohns 2018).

1.1 Problem Statement and Objectives

Canada has committed to decreasing its overall GHG emissions to 511 Mt CO_2eq by 2030. Given the GHG reduction target, energy and food security, it is critical to place a premium on second-generation biofuels. Some countries (e.g., the US and the EU) have issued mandates to stimulate advanced biofuel industries, thus increasing the production of second-generation biofuels. However, it is unclear how this kind of biofuel policy will influence the economy of Canada. To be specific, the new second-generation ethanol policies might affect Canada's industrial output, GDP, and employment. The possible macroeconomic impacts of developing this industry are needed. This study sheds light on this question and provides policy implications.

The objective of this study is to assess the macroeconomic impact of expanding the second-generation bioethanol industry, as well as the economic implications of different biofuel policy scenarios in Canada. The thesis applies an input-output analysis by incorporating a cellulosic ethanol industrial sector into the Canadian economy. This method can estimate the macroeconomic effect and provide details of the interindustry effect between a large number of sectors in the economy. The thesis uses the Canadian supply and use tables (SUTs) for 2017 from Statistics Canada. The SUTs are first expanded with new industrial sectors and products. Then an analytical adjustment approach proposed by Malik et al. (2014) is utilized to dynamically simulate the impact of producing second-generation biofuels to substitute for imported ethanol. The thesis estimates aggregate economic impacts of incorporating the new industrial sector on industrial output, GDP, and employment. It also provides insight into the linkages between the second-generation bioethanol industry and other industrial sectors in the economy. Given the base case scenario of import substitution for ethanol, the study further builds several policy scenarios to shock the model. These scenarios are simulated using the targets set by proposed first-generation ethanol substitution and second-generation bioethanol mandates. The analysis on possible changes leads to new insight into the policy mix in future.

1.2 Organization of the Thesis

The text is organized into 6 chapters, beginning with the introduction chapter that provides background information about biofuels production and policies. Chapter 2 reviews the literature and first summarizes the potential second-generation feedstock. This chapter also covers common methods of modelling the biofuel sector in the economy and identifies the benefits of rectangular input–output model. Chapter 3 outlines the construction of the I-O model used in this study. The existing Canadian supply and use tables are aggregated and then augmented to incorporate ethanol derived from crop residues. This chapter reviews a common method, RAS, employed to reconcile the input-output tables and describes the modified RAS method applied in this study. Chapter 4 presents the data used in the analysis. The cost structure of the second-generation biofuel industry based on agricultural residues in Canada is developed and illustrated. Then the interindustry effect of the new second-generation biofuel industry in Canada is estimated. The data on the GHG emissions derived from the gasoline pools are identified. The analysis is complemented by the change in GHG emissions in each scenario. Chapter 5 presents the results of several policy simulations and provides a discussion of the policy implications. Chapter 6 concludes and provides some policy suggestions. The limitations of this study are also discussed, as well as possible future research work.

Chapter 2: Literature Review

Many scientists and economists have focused their research on second-generation biofuels. The literature covers potential feedstocks (Section 2.1) and economy-wide modeling of biofuels (Section 2.2). Potential feedstocks include homogeneous feedstock, quasi-homogeneous biomass, non-homogeneous biomass, and plantation biomass. Economy-wide modeling of biofuels covers different methods applied to estimate the economic impacts of conventional and advanced biofuels, including partial equilibrium models, computable general equilibrium models, and input-output models. Section 2.3 provides a summary of the chapter.

2.1 Potential Feedstock of Second-Generation Biofuels

Biomass is an organic matter rich in carbon and several hydrogen molecules representing biofuel feedstock in general. Biomass comprises wood materials and residues, crops and residues, aquatic plants, etc. (Toor et al. 2013; Venkatachalam et al. 2022). Second-generation feedstock refers to non-edible biomass, especially non-edible lignocellulosic biomass (Lee and Lavoie 2013). Osmani and Zhang (2017) and Venkatachalam et al. (2022) further classify lignocellulosic biomass into perennial native grasses, crop residues, and woody materials. Lignocellulosic biomass is less expensive than first-generation feedstock (Lee and Lavoie 2013), which mainly contains lignin and cellulose (Sikarwar et al. 2017). Other biomass, such as waste vegetable oil, is also considered as potential feedstock (Bowyer et al. 2018).

Second-generation biomass includes agricultural residues, dedicated energy crops, forestry residues, municipal and industrial wastes, and other re-useable carbon sources (Gerber et al. 2013; Hamzah et al. 2020; Ho et al. 2014; Sikarwar et al. 2017; USDE 2021). Lavoie et al. (2011) and Lee and Lavoie (2013) separate lignocellulosic biomass into three classes. The first category is homogeneous feedstock (e.g., structural and furniture wood and chips). Quasi-homogeneous biomass is another class that includes agricultural and forest residues. The last category is non-homogeneous biomass (e.g., municipal solid wastes). Notably, another category is plantation biomass (i.e., dedicated energy crops) which is sometimes regarded as first-generation feedstock (Lavoie et al. 2011). The classification is followed in this subsection.

2.1.1 Homogeneous Feedstock

The homogeneous feedstock embraces one or more comparable species with similar chemical components (e.g., structural and furniture wood and chips for pulp manufacturing). It can be utilized as a feed for high-end commodities with fully-fledged markets; hence it is more costly and mostly purchased by structural wood or pulp and paper sectors (Lavoie et al. 2011). This category only considers the chips and particles that are inputs of value-added commodities like particle board and paper. However, other wood wastes from forest logging or processing are classified as quasi-homogenous feedstock.

As a forest-rich country (347 million hectares), Canada has developed a large forest product sector highlighting wood and paper production (Cambero and Sowlati 2016; Natural Resources Canada 2020c). Nevertheless, intense global competition and shrinking demand for newsprint in North America has had a major impact on the sector. On the other hand, available mill residues were projected to sustain an annual bioethanol production of 0.2–1.6 billion liters in Canada (Mabee and Saddler 2010). Forest-based biorefineries would be a downstream sector from the forestry sector (CCFM 2017) and could improve the competitiveness of the forest sector (Sims et al. 2008).

Current research focuses on a series of case studies in British Columbia (Cambero et al. 2014; Cambero and Sowlati 2016; Maier et al. 2019; Porth and EI-Kassaby 2015). The forestry industry is a major economic sector in British Columbia (Cambero and Sowlati 2016). In forest-rich regions like British Columbia (BC), forest dregs, mill wastes, and woody materials like Populus and Salix are primary bioethanol feedstocks (Porth and EI-Kassaby 2015). In 2016, the amount of woody biomass available for biofuel production in BC was projected to be approximately 21 million m^3 with forest logging leftovers comprising approximately 15.7 percent of the feedstock (IFS 2015; Nie and Bi 2018).

Homogeneous biomass has a large potential market and is far more expensive compared to the other two groups. Additional demand for these feedstocks would further increase their price and thus have negative effects on the pulp and paper industrial sector as well as other related sectors (Sims et al. 2008). Although quasi-homogeneous feedstock is less homogeneous and typically includes more ashes than the homogeneous feedstock, it does not compete with food and wood source and is easily accessible. Because of the lower competition and price, quasi-homogeneous biomass is preferred by cellulosic ethanol refineries (Lavoie et al. 2011).

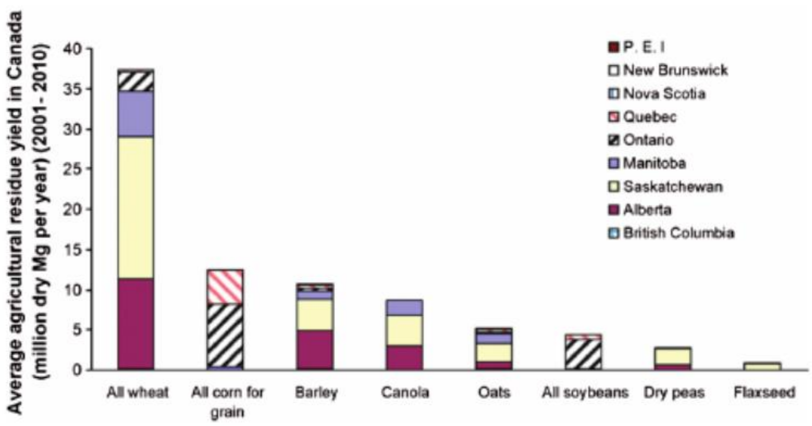
2.1.2 Quasi-Homogeneous Feedstock

Agricultural and forestry residues including different species are categorized as quasi-homogeneous biomass (Lavoie et al. 2011). Without requiring more acreage, abundant residues provide ready-to-use raw materials for the biofuel industry (Ho et al. 2014).

Agricultural residues refer to crop pieces left in the field after crops has been collected (Wang et al. 2020a). Wheat straw, corn stover, rice straw, sorghum stubble, and barley straw are examples of agricultural crop residues (Carpio and Souza 2017; Ho et al. 2014; Osmani and Zhang 2017; USDE 2021). Forestry residues are comprised of logging residues, forest thinning, and certain mill residues (Ho et al. 2014; Kocoloski et al. 2011; Osmani and Zhang 2017; USDE 2021).

The annual quantity of lignocellulosic biomass in Canada was calculated to be 64-561 million dry metric tonnes (MT) between 2001 and 2010 (Mupondwa et al. 2017). In fact, 82.4 million MT of agricultural residues are annually produced on average where wheat straw and corn stover are dominant harvested crops (Li et al. 2012a; Mupondwa et al. 2017; Scaife et al. 2015). Other residues including forest residues provides 9–49 million MT of biomass as potential second-generation feedstock (Blanco-Canqui et al. 2009; Mabee et al. 2006; Sokhansanj et al. 2006; Wood and Layzell 2003). If these residues were used for bioethanol production, the estimated total capacity could be 13 billion liters of bioethanol (Li et al. 2012a; Scaife et al. 2015).

Figure 2.1 Average Agricultural Residues Yield in Canada (2001-2010)



Source: Li et al. 2012a; Mupondwa et al. 2017

Moreover, farming regions in Canada that can produce agricultural residues include the Prairie provinces (i.e., Alberta, Saskatchewan, and Manitoba), Ontario and Quebec, where 96 percent of all Canadian agriculture takes place (Li et al. 2012a). The potential agricultural-based biofuel plants might be located in these provinces given the cost of feedstock harvesting and transportation (Scaife et al. 2015).

However, removing too much residue from farmland may have detrimental consequences for soil health (Schnepf 2010). If the agricultural residue is not harvested in a sustainable way, soil carbon will be lost and the erosion potential will increase ((S&T)^2 Consultants Inc. 2018). To avoid soil erosion, more than 0.75 ODT of crop residue should be left on each hectare of farmland (Stephen 2008; Stumborg et al. 1996). Moreover, agricultural wastes are also utilized for animal bedding, mushroom growing, horticulture, and other bioenergy production (e.g., heat, power, and biogas). Agricultural residue already collected for other specific purposes are not expected to be available as a biofuel feedstock (Searle and Malins 2016). Crop residues, on the other hand, were only bailed from 7.45 percent of farmland in Canada for on-farm purposes including livestock feeding and bedding in 2016 (Statistics Canada 2021a).

Forest residues are classified into leafy hardwoods and coniferous groups, and consist of useless trunk portions, branches, and tops (Lavoie et al. 2011). In Western Canada, harvesting forestry residue is traditionally gathered along roadsides and burnt to prevent forest fires (Kumar et al. 2003; Maier et al. 2019). Forest residues yielded approximately 2 million tonnes of wood pellets every year, accounting for 61 percent in Canada's total capacity (Bradburn 2014). However, 84 percent of Canadian wood pellets are exported to Europe (Natural Resources Canada 2020b). Therefore, the large and underutilized domestic forest residue supply, including harvesting residues and dead wood, could be a biofuel feedstock (Maier et al. 2019).

The amount of harvesting residues available in BC each year was reported to be 7.6-10.2 million oven dry MT (Yemshanov et al. 2014). In addition, 11 million oven dry MT of non-merchantable mountain pine beetle (MPB) dead trees could be used for energy production each year (Ralevic and Layzell 2006). One of the possible applications of forest-based waste in BC is to develop second-generation ethanol biorefineries (Nie and Bi, 2018). Therefore, prospective cellulosic ethanol plants from forestry biomass and residues might be located in BC (Maier et al. 2019).

2.1.3 Non-homogeneous Feedstock

Non-homogeneous feedstock is the third class. It is inferior to the other two categories (i.e., the homogeneous and quasi-homogeneous) and almost always free of charge. Despite the low cost of feedstock, biofuel conversion is more expensive since non-homogeneous biomass must be converted to a more homogeneous intermediate in advance (Lavoie et al. 2011).

Common municipal and industrial wastes embrace non-recyclable organic component of municipal solid waste, biosolids, sludges, waste food, plastics, CO_2, industrial waste gases, and manure slurries (Hamzah et al. 2020; Singh et al. 2017; USDE 2021). Human activities annually produced about 1.3 billion tons of municipal solid waste (MSW) around the world, in which papers, cardboards, and plastics can be regarded as potential feedstock (Jungmeier et al. 2013). Fruit and vegetable waste, sugar and starch residues, and animal product waste might all be utilized as possible source of biofuel production (Ho et al. 2014). It is noteworthy that used cooking oil as well as animal fats have been collected for second-generation biodiesel, particularly in Europe (Foteinis et al. 2020). Moreover, food and paper sectors generate numerous residues and by-products and thus the industrial waste may be utilized for biofuel production. For that reason, bioethanol applications from non-homogeneous feedstock have positive environmental impacts such as reduced landfill space and GHG emission reduction (Ho et al. 2014).

2.1.4 Dedicated Energy Crops

Dedicated energy crops are another controversial category of second-generation feedstock. This group includes perennial grasses and short rotation forestry (Ho et al. 2014). To be specific, common dedicated energy crops include miscanthus, switchgrass, reed canary, Jerusalem artichoke, hybrid poplars, shrub willow, Jatropha curcas Linnaeus, high biomass sorghum, energy cane, and sweet sorghum (Hamzah et al. 2020; Osmani and Zhang 2017; Thomassin and Baker 2000; USDE 2021). These plants can be cultivated on the poor soils of marginal land and have a broad geographical distribution. They produce greater energy yields and provide a consistent supply stream, significantly reducing storage costs between harvests (Ho et al. 2014; Lavoie et al. 2011).

Switchgrass and hybrid poplar are widely regarded as viable feedstock for biorefineries (Heaton et al. 2008; Perlack et al. 2005; Scaife et al. 2015; Wright and Turhollow 2010). Perennial grasses like miscanthus and switchgrass are among the best choices in North America and Europe due to their cold temperature tolerance and the ability to grow on a wide range of land types using conventional farming practices (Lewandowski et al. 2003; Osmani and Zhang 2017; Roy et al. 2015; Sokhansanj et al. 2009). Also, certain short rotation wood crops have the potential to be biofuel feedstock due to their lower costs and labor requirements in comparison with annual plants (Hauk et al. 2014). Among the species, poplar, willow (common in temperate areas), and eucalyptus (mostly in tropical areas) are species cited the most. Another preferred feedstock might be Jerusalem artichoke, since it could improve soil quality when included in rotations (Thomassin and Baker 2000).

Available marginal land in Canada was projected to be about 5.3 million hectares, enough to produce up to 17.3 million MT of annual energy crops (Mabee et al. 2006). Biofuels from energy crops can alleviate land use to a certain extent. Perennial grasses and short rotation forestry are preferable to annual agricultural crops since they might not compete for farmland with existing agricultural commodities (Osmani and Zhang 2017; Sokhansanj et al. 2009). Nonetheless, plantation biomass is still land-based, so they cannot completely avoid the food versus fuel debate (Weng et al. 2019). While plantation biomass can be produced on marginal land, better sites generate larger harvests, complicating farmers' land use decisions (Bowyer et al. 2018). Furthermore, large-scale energy crop production might be harmful to local ecosystems and biodiversity (Groom et al. 2008). It is critical to evaluate if planting biofuel crops threatens local biodiversity as well as water and nutrient cycles (Scaife et al. 2015; Dominguez-Faus et al. 2009). Pesticides and fertilizers issues are also associated with these plantations, especially for switchgrass (Bowyer et al. 2018).

2.2 Application and Comparison: Modelling Exercises

In general, second-generation biofuels improve environmental consequences compared to first-generation biofuel in terms of water and land use as well as carbon emissions (Scaife et al. 2015). However, the impact of second-generation biofuel production varies depending on technologies and feedstocks (Bowyer et al. 2018; Trømborg et al. 2013; Wang et al. 2020b). These biofuel feedstocks and land used for production should be carefully chosen since the cultivation may negatively influence certain sustainability criteria such as biodiversity conservation, erosion control, and local fuelwood supply (Havlik et al. 2011).

Land use is one of the primary concerns when selecting second-generation feedstock. The anticipated increase in energy crop production may still affect the availability of cropland (De Lucia and Bartlett 2014). Doubling Canadian ethanol production with cellulosic ethanol from plantation biomass would further occupy 0.30 million hectares of farmland and 0.57 million hectares of pasture (Campbell 2018). Therefore, enforcing a cellulosic mandate might be expensive because it will raise the equilibrium price of feedstock through acreage competition (Baker et al. 2008; Mallory et al. 2011). Advanced biofuels produced from agricultural residues, forestry residues, and municipal wastes, on the other hand, may alleviate the pressure on acreage without using additional land (Pinales-Márquez et al. 2021; Bryngemark 2019). The study of Taheripour and Tyner (2013) also indicated that converting agricultural wastes to biofuel led to no substantial ILUC emissions, however, this was not the case with dedicated energy crops. So agricultural residues might not cause additional land use change (Mosnier et al. 2013).

Another important point is carbon emissions of feedstocks. The case study of Osmani and Zhang (2017) showed that in Wisconsin crop residue would have the lowest GHG emissions during feedstock procurement. While woody biomass might have the highest GHG emissions, switchgrass would be the most cost effective and moderately environmentally sustainable. Wang et al. (2020a) further argued that liquid biofuels from forestry biomass would be prohibitively expensive in Canada at present carbon tax levels.

Researchers are also concerned about potential risks and limitation of controversial feedstocks (Scaife et al. 2015; Pandiyan et al. 2019). When it comes to perennial grasses and woody plant species, biological invasion is a major concern (Smith et al. 2013). For example, approximately 35 million hectares of land was invaded by Parthenium sp., which caused approximately a 40% loss in agricultural output (Pandiyan et al. 2019). Additionally, exotic trees (e.g., hybrid poplar) are also prohibited on crown lands under Canadian forestry law (Campbell 2015).

Crop residues are readily available with more environmental benefits and less limitations. They are preferred when collected in a sustainable way compared to other feedstocks and become the targeted second-generation feedstocks in this analysis.

2.2.1 Economy-Wide Modeling of Biofuels

To assess the economic effect of biofuel production and policy, a variety of economy-wide analytical methods have been employed. These include input-output analysis (IO), partial equilibrium (PE), computable general equilibrium model (CGE), as well as life cycle assessment (LCA). Several studies have integrated different analytical tools. These models have been extensively used to evaluate first-generation biofuel policies (Blanco et al. 2013; Malik et al. 2015; Mukhopadhyay and Thomassin 2011; Taheripour and Tyner 2011a; Urbanchuk 2020). With second-generation biofuel sector and policy development, some studies have focused on the economy-wide effect of these biofuels (Eisentraut 2010; Reijnders 2013; Scaife et al. 2015). On the other hand, although the biofuel industry based on lignocellulosic feedstock has the potential to yield sustainable processes, economic assessment of second-generation biofuels is still in its early stage. Only a small amount of work has been done in Canada.

2.2.2 Partial Equilibrium Model

Partial equilibrium (PE) models are intended to simulate different products within a certain sector (usually agriculture) in several regions. Common global recursive dynamic PE models include AGLINK-COSIMO model developed by Organization for Economic Co-operation and Development and the Food and Agriculture Organization (Araujo-Enciso et al. 2017), as well as the Global Biosphere Management Model (GLOBIOM) proposed by the International Institute for Applied Systems Analysis (IIASA 2014). Another category is global static PE models, including Common Agricultural Policy Regionalized Impact (CAPRI) Modelling System proposed by University of Bonn and the EU highlighting Europe (CAPRI 2020), the FAPRI model designed by Food and Agriculture Policy Research Institute (Fabiosa et al. 2010), and the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) established by the International Food Policy Research Institute (IFPRI). The European Simulation Model (ESIM) is a multi-regional, comparative static PE model focusing on agricultural sector (Fonseca et al. 2010). The effect of biofuel production and regulations on the agricultural markets has been studied using these PE models (Babcock 2012; Blanco et al. 2013; Burrell et al. 2012; Fabiosa et al. 2010; Fonseca et al. 2010; Havlik et al. 2011; Le Roy et al. 2011; Rosegrant 2012).

(1) First-Generation Biofuel Research

Several worldwide or multi-regional PE models have been extended to include first-generation biofuel markets. Utilizing AGLINK-COSIMO, CAPRI, and ESIM models, Fonseca et al. (2010) examined the change of global agricultural production and markets driven by the EU biofuel mandate (10% from biofuels in the transport sector). The consequences in EU included higher imports and domestic supply of both biofuel (i.e., ethanol and biodiesel) and feedstock (e.g., vegetable oil). Nonetheless, the global impact was trivial.

Durham et al. (2012) and Hélaine et al. (2013) further used the AGLINK-COSIMO model to estimate the feedstock price change caused by biofuel mandate. Durham et al. (2012) simulated the absence of biofuel mandates when there is a spike in grain prices. Their study concluded that the removal of US and EU biofuel mandates could avoid around 40% and 15% of projected coarse grain price surge, respectively. Hélaine et al. (2013) found the removal of EU biofuel policy would significantly reduce (15%) the world market price of vegetable oils while the changes in other feedstock prices were relatively small (at most 5%). The FAPRI model was used to assess the economic effects of bioethanol production and subsidies in the US on the grain and livestock sectors (Babcock 2012). The results indicated that corn ethanol production increased crop prices significantly and food prices modestly while ethanol subsidies might not have the same effect.

Other economists have developed their own PE models to incorporate biofuels. McPhail and Babcock (2012) developed a PE model and found that both the Renewable Fuel Standard (RFS) and blend wall in the US reduced maize and gasoline's price elasticity of demand and thus increased the price volatility as supply shocks occurred.

Another example of this approach is Nuñez et al. (2013). They developed a price endogenous mathematical programming model and indicated that biofuel expansion driven by mandates raised economic growth by 1% in Brazil and the US and reallocated agricultural consumers' benefits to agricultural and fuel producer. In the US, even though cellulosic biofuel satisfied approximately half of mandated demand, other corn ethanol still raised corn price by 2%. In Brazil, the sugarcane expansion would require more intensified livestock production with less pasture.

In general, first-generation biofuel expansion might increase agricultural output, especially biofuel feedstock, while raising prices of feedstocks and foods. On the other hand, food and fuel markets tend to be relatively volatile and the development of biofuel feedstock may further exacerbate the volatility. Higher fuel prices may stimulate farmers to provide biofuel refineries with crops and thus decreasing available food crops. It results in knock-on effects in the food sector as well as rippling effects in both markets (Scaife et al. 2015). However, when there are more advanced biofuels than are required by mandate, the impact of the mandate (e.g., U.S. RFS) on price volatility may be mitigated (McPhail and Babcock 2012).

(2) Second-Generation Biofuel Research

Few studies have used PE models to evaluate the economic effect of second-generation biofuel from forestry biomass in Europe and Canada. Bryngemark (2019) added a second-generation biofuel module to the Swedish PE model of forest raw material markets and investigated the impact of second-generation biofuel production (5-30 TWh) on the forest feedstock (e.g., harvesting residues) market. The findings indicated that rising prices of byproducts (e.g., sawdust) in the forest sector was the result of intense competition for forestry raw materials. Manufacturing fiberboard and particleboard was halted because of costly inputs, while increased byproduct prices motivated sawnwood production and forest harvesting. Hope et al. (2020) also developed a Monte-Carlo-based PE model to predict the price change of biofuel feedstocks (i.e., forest residues) in Canada. Considering carbon pricing and biofuel refining revenue from Clean Fuel Standard (CFS) credits, the price of fossil fuels was expected to increase significantly. The composite panel sector, which used forest residues as an input, may be harmed due to the price rise of fossil fuels.

These studies suggest that biofuel refineries typically intensify the competition for feedstock, such as residues and chips. However, biofuel production from forest residues may be more advantageous than biofuel production from wood considering the impact on the forest sector. Trømborg et al. (2013) used a PE model for the forest and energy industry to conclude that the wood-based biofuels sector would decrease bioheat production by 5-20 percent through biomass competition in Norway. For this reason, residues and wastes that have not been collected for a specific purpose or underutilized may be better choices. They also revealed that second-generation biofuel production from a wide range of wood biomass species experienced lower biomass prices than technologies using only one species as raw material, alleviating the negative effect on bioheat and forest production. Chudy et al. (2019) further developed a dynamic PE model and analyzed how wood-chip-based biofuel production influenced the forest sector in Norway. The results indicated that a medium-scale biofuel plant had a minimal impact on the domestic forest sector since the effect is decreased by international trade, particularly chip imports. This implied relatively high leakage resulting in outflow from the domestic area.

One disadvantage of partial equilibrium models is that they have limited scope in comparison with general equilibrium models. General equilibrium models are able to include a larger number of sectors in their analysis.

2.2.3 Computable General Equilibrium Model

Computable General Equilibrium (CGE) modelling is a widely used technique to estimate the economic and environmental impact of changes in external factors. An advantage of CGE models is that they are applicable to a variety of technical specifications. The model also takes into account direct and indirect effects of external changes and is a substantial tool for modelling scenarios (Doumax-Tagliavini and

Sarasa 2018; Kretschmer and Peterson 2010). CGE models typically incorporate multi-regions, numerous sectors, as well as product and factor markets. Therefore, the framework provides a broader perspective on economic effects driven by external shocks.

The Global Trade Analysis Project (GTAP) is the most comprehensive and widely used CGE modelling framework (GTAP 2015a). The GTAP-E model was designed to estimate the cost of reducing pollution and to account for GHG emissions related to regional interactions and industrial connectedness (GTAP 2015b). Another model using this framework was the GTAP-BIO model which incorporated first-generation biofuels and GTAP-BIO-ADVF model which comprised second-generation biofuels (Taheripour et al. 2007; Birur et al. 2008; Taheripour et al. 2011b; Taheripour and Tyner 2011a).

Popular dynamic-recursive global CGE models include Dynamic Applied Regional Trade (DART) proposed by the Kiel Institute (Calzadilla et al. 2014), Emissions Prediction and Policy Analysis ((EPPA) proposed by Palstev et al. (2005), and WorldScan developed by CPB Netherlands Bureau for Economic Policy Analysis. Another common CGE model is Modelling International Relationships in Applied General Equilibrium (MIRAGE). It can be applied dynamically or statically (MIRAGE 2011). These models have been extended to incorporate biofuel production (Al-Riffai et al. 2010; Banse et al. 2008a; Banse et al. 2008b; Birur et al. 2008; Boeters et al. 2008; Britz and Hertel 2011; Cansino et al. 2013; Doumax et al. 2014; Gurgel et al. 2008; Hertel et al. 2008a; Kretschmer and Peterson 2010; Kretschmer et al. 2009; Ogg 2009; Reilly and Paltsev 2009; Rosegrant et al. 2008; Taheripour and Tynes 2014; Taheripour et al. 2011a; Taheripour and Tyner 2011b; Wianwiwat and Asafu-Adjaye 2013).

(1) First-Generation Biofuel Research

CGE models have been developed to evaluate the macroeconomic effect of first-generation biofuels, particularly on agriculture. Timilsina et al. (2012) applied a dynamic GTAP model with biofuel sectors to analyze long-term aggregate economic impacts of large-scale biofuel expansion to achieve current or higher targets worldwide. They found that biofuel expansion in countries that had targets would result in a small reduction in global GDP, but the effects varied by country and region. Arndt et al. (2012) applied a dynamic national CGE model and announced that a cassava-based biofuel industry increased national GDP and generated new jobs in Tanzania.

The interindustry effect of first-generation biofuel expansion tends to be concentrated in the agricultural sectors. According to Campbell (2018), except primary agriculture and forest sectors, there are minimal interindustry effects by doubling first-generation biofuel production in Canada. Transport and utility sectors could be impacted, however. A case study in the EU showed that oil and electricity prices were expected to decrease (De Lucia and Bartlett 2014).

In studies where the agricultural sectors is the central focus, the effects of biofuel production on agricultural output, commodity prices, and trade are critical. Timilsina et al. (2012) showed that increased biofuel production would lead to a modest decline in global food supply whereas developing countries such as India and Sub-Saharan Africa would experience a more significant decrease. Feedstock prices, including sugar, maize, and oil seeds, would substantially increase in 2020 with minor changes in other prices. In addition, De Lucia and Bartlett (2014) indicated with a CGE model that biorefineries using oilseeds and their by-products in the EU would cause a significant increase in the supply of this crop (produced mainly in Eastern Europe) while reducing sectoral GDP in many other regions. Another study found that the expansion of the US and EU biofuel sectors might lead to a greater absolute decrease in livestock production overseas than in the regions with domestic biofuel sectors (Taheripour and Tyner 2011a).

Economists have held differing opinions on the national impact of first-generation biofuels on food supply. Some have argued that the negative effect might be transmitted to biofuel producing regions or certain developing countries. Weng et al. (2019) developed a national CGE model and found that increasing bioethanol production would lead to a 0.1 percent increase in food prices driven by a new nationwide E10 mandate in China. The effect was lessened by reclaiming marginal land. Wianwiwat and Asafu-Adjaye (2013) developed a national CGE model highlighting the energy sector in Thailand. They came to the conclusion that biofuel use might cause a significant increase in biofuel and feedstock prices in the near term, while the increase would become smaller in the long term because of more elastic supply.

(2) Second-Generation Biofuel Research

CGE models have been extended to incorporate second-generation biofuels (Boeters et al. 2008; Du Lucia and Bartlett 2014; Gurgel et al. 2007, 2008; Melillo et al. 2009; Reilly and Paltsev 2009; Taheripour and Tyner 2013; Taheripour et al. 2010b). The economic-wide research highlighted the case study of energy crops in Canada and the EU with agricultural sector still receiving attention.

In general, second-generation biofuels benefit food security. Agricultural commodities would see a decrease in price when second-generation biomass was utilized as biofuel feedstocks in the EU (Banse et al. 2008c). However, energy crops are controversial feedstocks. When energy crops were produced for biofuel refining, the downward trend in prices of agricultural commodities would change. The higher land price was less competitive in the global market, negatively influencing farmers (De Lucia and Bartlett 2014). Doumax and Sarasa (2018) further modified the recursive dynamic CGE model in Doumax et al. (2014) for the French economy to evaluate the consequences of the EU advanced biofuels policies. The results suggested that the increase in biofuel prices was not translated to food prices when advanced feedstocks included lignocellulosic materials and wastes. Hence, second-generation biofuel from various species tends to alleviate pressure on food supply overall but biofuel production from energy corps may still threaten food security.

Campbell (2015, 2018) modified the static GTAP-BIO-ADVF model with 43 commodities, 19 regions and biofuel feedstock (i.e., hybrid poplar) to examine the impact of doubling domestic conventional or cellulosic ethanol supply in Canada. Campbell (2015) found price and output changes were less than 10 percent with hybrid poplar as the feedstock. The agriculture sectors had larger increase than the forestry sectors. Moreover, given marginal land use for hybrid poplar production, Canadian cellulosic ethanol would have smaller inter-industry effects (i.e., price and output change) than first-generation ethanol. Campbell's (2018) study further compared the effect of doubling starch-based and cellulosic ethanol production and showed the latter had positive impacts on the Canadian economy. First-generation biofuel production increased coarse grain yield by 9 percent with a 6 percent increase in price, while second-generation production decreased coarse grain output by 1 precent with at most a 1 percent increase in price. Second-generation production might lessen production loss in grains and oilseed by 20–25 percent in comparison with first-generation production. Nonetheless, hybrid poplar competed for marginal land and impacted cattle grazing significantly. Cattle output fell by 1.5 percent and cattle prices increased by 2 percent due to second-generation production, while the changes are minimal for first-generation biofuel. Hence, biofuels made from hybrid poplar might also be criticized for possible repercussions such as marginal land use and livestock decreases.

2.2.4 Input-Output Model

Input-Output (IO) analysis is another common economy-wide analytical technique and is a valuable tool in research and policy analysis. It can estimate the impact of changes in final demand on total industrial sector output, income, and employment, and provide a detailed accounting of the macroeconomic aggregates and monetary flows. In addition, the IO model is useful for examining the relationships between certain sector and the whole economy. It can provide the direct, indirect, and induced effects, as well as a comprehensive description of the impacts (Plevin et al. 2014). Moreover, it can have a greater disaggregation of industrial sectors and commodities with the rectangular framework compared to CGE models.

The input–output framework has been extended to estimate environmental pollution accumulation and reduction caused by interindustry flows (Miller and Blair 2009). Life cycle analysis (LCA) is often integrated into IO models to assess the environmental impact of biofuels. The linearity of the relation between output and effects is a fundamental assumption in IO analysis. Attributional LCA shares this presumption, while consequential LCA does not. The attributional LCA works by assigning a percentage of the global effects to a specific product (Mattila 2018). The Food and Agricultural Policy Simulator (FAPSIM) and Impact Analysis for Planning (IMPLAN) are examples of IO-based LCA methods and are employed in analyzing biofuel policies in the US (Hart et al. 2012; Joshi et al. 2012; Schlosser et al. 2008; Urbanchuk 2020; Urbanchuk and Norvell 2017).

(1) First-Generation Biofuels

A series of first-generation biofuel studies have been undertaken for regional IO modelling systems to estimate the economic effect and provide insight into the linkages between regions. For example, a case study for nine ASEAN countries used an inter-regional IO model with 23 sectors for 14 countries (Kunimitsu et al. 2013). The results showed that bioethanol production increased agricultural production and the agriculture contributed was half of the overall induced effect. However, the interregional spillover effects appear to be significant. Martínez et al. (2013) used an inter-regional IO model with 34 sectors and three areas to show that sugarcane-ethanol production in Northeast Brazil raised local employment by 10% -126% by 2020. The value added of the sugarcane–ethanol industry was estimated to be $2.8-9.4 billion US dollar in the Northeast Brazil.[1] Significant positive impacts might also be realized for the rest of Brazilian economy.

Urbanchuk and Norvell (2017) applied the IMPLAN model to the economy of Minnesota to estimate the impact of the biofuel sector. They showed that ethanol refineries yielded over $1.9 billion in GDP and created 18,000 full-time jobs for Minnesota. Urbanchuk (2020) further constructed a model of the U.S. economy with

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[1] The variation in the estimates were the results of additional scenario simulations. The higher estimates in the other two scenarios were based on the assumptions of more efficient agricultural practices and processing efficiency or an expansion of the sector into new areas compared to the Business as Usual.

IMPLAN multiplier database. The total impact of the ethanol sector added approximately $35 billion to GDP with the ethanol manufacturing activity alone generating $9.5 billion in 2020. The total employment and income provided by the ethanol sector was estimated to be nearly 305,000 jobs and $19 billion in 2020. The interindustry effects still highlight agriculture. Farmers benefit the most from increased feedstock demand that resulted in higher output and prices, as well as revenues from local ethanol refineries.

Malik et al. (2014) modelled sugarcane-based ethanol as a latent technology in the IO framework and utilized a modified RAS method to evaluate the economic consequences of substituting petroleum for ethanol in Australia. The findings found that the upstream alcohol sector experienced an increase in output, while the petrol refinery sector had a decrease in output. This method is advantageous since it traces the development through the RAS method and provides detailed information. In the early stage, the new biofuel industry generated around 2,000 jobs. The negative effect on the petroleum supply chain would become effective later, shrinking total job creation. This modified RAS method has been used in the thesis to track the evolution of the Canadian economy driven by the second-generation ethanol industry.

The IO models above are all symmetric models. Several studies have applied rectangular commodity–industry models to specially explain secondary production like co-products and by-products (Miller and Blair, 2009). Mukhopadhyay and Thomassin (2011) used a rectangular IO model of Canada to analyze the macroeconomic impact and GHG emission reductions of developing an ethanol sector in Canada. They introduced two new biofuel industries into the Make and Use tables of the Statistics Canada’s 2003 SUT, biofuel and E10, with four new commodities comprising ethanol, DDG, E10, and CO2. Mukhopadhyay, Chen, and Thomassin (2017) further estimated how the mandates and the gap in consumption and production of biofuels impacted the Canadian economy by introducing four new industries (ethanol, biodiesel, E10, and B5) with additional products (DDG, glycerin, canola meal, CO2, ethanol, biodiesel, E10, and B5) into the Canadian IO model in 2008. This study showed the that total biofuel industry generated 13,286 million dollars (0.59 percent of total industry output) and 6,164 jobs (0.04% of total employment). First-generation biofuel contributed to increase GDP by 748.88 million dollars (0.052% of the total GDP). As the main upstream sector, agriculture is the most impacted. Mining and manufacturing sectors, as well as finance, insurance, transportation, and services sectors, all had significant impacts. This study follows the Mukhopadhyay and Thomassin (2011) and Mukhopadhyay, Chen, and Thomassin (2017) and employed the Canadian rectangular supply and use tables in the analysis since by-products might influence the estimates.

Other IO model examples include Cunha and Scaramucci (2006) for Brazil and Neuwahl et al. (2008) for the European Union. In addition, some papers applied IO analysis to study the environmental consequences of first-generation biofuels (Castillo et al. 2019; Liang et al. 2013; Silalertruksa et al. 2012b).

In general, first-generation biofuel production has a strong positive aggregate effect on the economy and significantly benefits the agriculture sectors (Silalertruksa et al. 2012a). However, the economic and environmental gains from second-generation biofuel production might be much higher (Mukhopadhyay et al. 2017).

(2) Second-Generation Biofuel Research

Research on the advanced feedstocks using IO-LCA model is noteworthy. Examples of lignocellulosic biomass include Festel et al. (2014), Malik et al. (2016), Ou et al. (2009), Singh et al. (2010), Yue et al. (2014), and that of microalgae covering Lardon et al. (2009) and Malik et al. (2015). Recent economic-wide studies tend to apply symmetric multi-region input-output (MRIO) combined with LCA to assess economic and environmental effects of advanced biofuels expansion, especially when designing supply chains.

Malik et al. (2015) applied the Australian MRIO tables constructed by Lenzen et al. (2014) with 344 industrial sectors and 19 regions to measure the effect of algal bio-crude refining in Western Australian. One million tonnes of bio-crude supply would result in around 13,000 additional jobs and 4 billion Australian dollars in economic growth. Using the same MRIO framework, Malik et al. (2016) further quantified the effects of biofuel production from forestry biomass in the Green Triangle region of South Australia. They revealed that new ethanol production resulted in 2500 new jobs and $815 million Australian of economic stimulus. The advanced biofuel sectors in Malik et al. (2015; 2016) were shown to be a net carbon sequester with a supply chain more sustainable than that of crude oil.

Wang et al. (2020b) further developed a hybrid MRIO-LCA model incorporating 42 sectors and 31 provinces to compare the impacts of first- and second-generation ethanol industry on the Chinese economy. Each one million yuan of first-generation (second-generation) bioethanol output in China would generate 1.92 (1.78) million yuan in economic gains with 2.06 (1.93) full-time equivalent jobs. The second-generation refining, on the other hand, provided far lower energy consumption (1.19 TJ) than first-generation production (2.00 TJ). They also showed that bioethanol refining led to more economic gains and energy efficiency, but less new jobs in comparison with petroleum manufacturing.

These studies shed light on the economic and environmental benefits of second-generation biofuels. Although second-generation refining might have slightly lower economic stimulus compared to first-generation production, its environmental consequences (e.g., GHG emission reduction and energy saving) tend to substantially outperform first-generation. These studies all apply symmetric IO models, thus the details of certain byproducts might be omitted during the analysis. The rectangular IO framework may provide more precise estimates.

2.2.5 Discussion

In summary, previous methodologies highlight two points when modelling advanced biofuel production for macroeconomic analysis. First, economists tend to model biofuel as a latent technology at this stage (Doumax-Tagliavini and Sarasa 2018; Malik et al. 2014). For example, Wianwiwat and Asafu-Adjaye (2013) suggested that biofuels could be modeled as latent technologies in the context of CGE (Gurgel et al. 2007; Melillo et al. 2009; Reilly and Paltsev 2009). The other two approaches for modeling biofuel include representing biofuels by crops that keep the original model structure unchanged and disaggregating existing commercialized biofuel industry from available databases.

Second, biofuel by-products should be considered and incorporated into the model since they might influence aggregate economic effects and interindustry effects significantly (Blanco et al. 2013; Fonseca et al. 2010; Mukhopadhyay and Thomassin 2011; Saladini et al. 2016; Wang et al. 2020a; Zhao et al. 2016). Taheripour et al. (2010a) argued that earlier research tended to overestimate the effect of first-generation biofuel because they overlooked the impact of biofuel by-products. Therefore, economists are placing more attention on biofuel by-products in their analysis.

To estimate the macroeconomic effect of second-generation biofuels in Canada, this study uses a rectangular IO framework to incorporate a second-generation biofuel sector based on agricultural residues. The IO framework is preferred to a CGE model since it can incorporate more industrial sectors and detailed byproducts. In addition, forest residues are an alternative feedstock, but previous studies have shown potential negative effects on downstream sectors of forest sector (Hope et al. 2020; Bryngemark 2019; Trømborg et al. 2013). Moreover, second-generation biofuel technology is modeled as a latent technology since no commercial ethanol refineries from agricultural residues exist in Canada today.

When incorporating new industries and commodities into the IO framework, it involves the augmentation of tables that causes imbalance. One common method to rebalance the model is the RAS method, thus the thesis reviews the literature of this technique in Chapter 3: Methodological Framework.

2.3 Summary

Previous research has been undertaken in the field of biofuels. The literature covers the various biofuel feedstocks, modelling methods, and economic-wide impacts of biofuels.

Past research has shed light on crop residues in Canada. This feedstock may both alleviate pressure on land and have higher GHG reductions. Moreover, agricultural residues are largely not used in Canada, the competition for the feedstock might be minimal. The main problem of soil health (i.e.., soil erosion) can be solved by leaving a certain rate (e.g., over 7.45%) of residues on cropland for on-farm use. Considering wheat and corn residues are the largest agricultural residues in Canada, the thesis regards them as the main second-generation biomass feedstock in the analysis.

In addition, the input-output analysis is preferred because it is more useful to investigate relationships between the biofuel industry and the whole economy. Importantly, it could have more disaggregated agricultural sectors as well as other industrial sectors. For that reason, the thesis emphasizes the effects on these industries.

A gap in the literature is that previous studies have not incorporated a bioethanol sector from agricultural residues in the Canadian economy. Therefore, the study contributes to the literature by estimating the macroeconomic effect of corn-stover-based bioethanol production.

Chapter 3: Methodological Framework

The thesis uses input-output analysis to estimate the macroeconomic effect of second-generation biofuel on the Canadian economy. The rectangular SUT framework is used to apply the RAS method to balance the model and further examine the interindustry effects of a cellulosic ethanol industry. Therefore, this chapter first introduces the basic structure of the input-output model (Section 3.1) and the method used to the construct the modified model augmented with second-generation biofuel products and industries (Section 3.2). The RAS method is reviewed in Section 3.3 and the modified RAS technique used in the thesis is described in Section 3.4. Finally, we summarize the highlights of this chapter (Section 3.5).

3.1 Basic Input-Output Model

The input-output model is constructed from input-output tables (IOTs) that are derived from supply and use tables (SUTs). A rectangular input-output model is constructed based on the SUTs to estimate the macroeconomic effect of technical change (Miller and Blair 2009). The data is measured in monetary terms.

In the Use table, the $m \times 1$ vector of total product demands $\boldsymbol{q^d} = [q_i^d]$ can be written as:

$$\boldsymbol{q^d} = \boldsymbol{U}\boldsymbol{i} + \boldsymbol{e} \tag{3.1}$$

where the Use matrix $\boldsymbol{U} = [U_{ij}]$ is a $m \times n$ matrix and U_{ij} is the purchases of product i by industry j, and the vector $\boldsymbol{e} = [e_i]$ represents commodity i's sales to final demand. The vector $\boldsymbol{i}$ denotes a row summation operator. Equation (3.1) shows that the total demand for each product is equal to the sum of its intermediate and final demand. On the other hand, the vector of total sectoral inputs $\boldsymbol{x^{in}} = [x_j^{in}]$ is a $n \times 1$ vector:

$$\boldsymbol{x^{in}} = (\boldsymbol{U^T})\boldsymbol{i} + \boldsymbol{v} \tag{3.2}$$

where the vector $\boldsymbol{v} = [v_j]$ represents the value added of industry j and the superscript

T denotes the transpose of the matrix. Industry technology coefficients are defined as $B_{ij} = U_{ij}/x_j^{in}$ (purchases of commodity i as a percentage of total inputs in industry j) and then the corresponding $m \times n$ matrix ($\boldsymbol{B}$) can be expressed as:

$$\boldsymbol{B} = \boldsymbol{U}\widehat{\boldsymbol{x^{in}}}^{-1} \tag{3.3}$$

where the hat symbol '^' denotes vector diagonalization. Hence, $\boldsymbol{B}$ and $\boldsymbol{e}$ can link total sectoral inputs to total demand of products:

$$\boldsymbol{q^d} = \boldsymbol{Bx^{in}} + \boldsymbol{e}. \tag{3.4}$$

Similarly, in the Supply table, total sectoral output $\boldsymbol{x^{out}}$ can be expressed as:

$$\boldsymbol{x^{out}} = \left(\boldsymbol{V^T}\right)\boldsymbol{i}, \tag{3.5}$$

where the Supply matrix $\boldsymbol{V} = [V_{ij}]$ shows the supply of product i made by industry j. Then the vector of total commodity supply $\boldsymbol{q^s}$ can be written by

$$\boldsymbol{q^s} = \boldsymbol{V\,i}. \tag{3.6}$$

The market share coefficient can be defined as $D_{ji} = V_{ij}/q_i^s$ which is derived by each element in row i of the Supply matrix divided by the i^th row sum, q_i. Therefore, D_{ji} denotes the proportion of product supply from industry j in total supply of product i. The market shares matrix ($\boldsymbol{D} = [D_{ji}]_{n\times m}$) can be defined as:

$$\boldsymbol{D} = \boldsymbol{V^T}\widehat{\boldsymbol{q^s}}^{-1}, \tag{3.7}$$

which interconnects each product supply and every sectoral output:

$$\boldsymbol{x^{out}} = \boldsymbol{Dq^s} \tag{3.8}$$

To estimate the impact of a change in final demand on industrial output, Equation (3.4) is incorporated into Equation (3.8) if $\boldsymbol{x^{out}} = \boldsymbol{x^{in}}$ and $\boldsymbol{q^s} = \boldsymbol{q^d}$. The sectoral outputs can be derived from:

$$\boldsymbol{x} = (\boldsymbol{I} - \boldsymbol{DB})^{-1}\boldsymbol{De} \tag{3.9}$$

The industry-by-commodity total requirement matrix $(\boldsymbol{I} - \boldsymbol{DB})^{-1}\boldsymbol{D}$ can be used to assess the total effect on sectoral outputs caused by a change in final demand.

3.2 Modification to the Input-Output Model

To focus on the macroeconomic effect in the domestic economy, the effect of leakages is considered in the analysis, competitive imports are first removed from the SUTs (Section 3.2.1). Then the IO framework is aggregated based on the Canadian SUTs for 2017 (Section 3.2.1). The SUTs are further augmented by certain rows and columns with corresponding data for the new biofuel sectors and commodities (Section 3.2.3). This step creates an imbalance in the original model. As a result, the RAS-type method is used to reconcile the model and evaluate the impact caused by second-generation production (Section 3.4). This step is useful to trace the economy during the period of adjustment. The direct and indirect effect is estimated for the construction of the second-generation plant and annual operation of the plants on sectoral outputs, GDP, and employment (Section 3.2.4).

3.2.1 Removing Competitive Imports

Before aggregation, competitive imports are removed from the intermediate inputs. The initial Use matrix ($\boldsymbol{R} = [R_{ij}]$) can be expressed as:

$$\boldsymbol{R} = \boldsymbol{U} + \boldsymbol{P} \qquad (\mathbf{3.10})$$

where $\boldsymbol{U}$ represents the matrix of domestic transactions, and $\boldsymbol{P}$ denotes the matrix of transactions from competitive imports. According to Miller and Blair (2009), the competitive imports can be estimated by

$$\boldsymbol{P}^{*} = \widehat{\boldsymbol{H}}\boldsymbol{R} \qquad (\mathbf{3.11})$$

where $\widehat{\boldsymbol{H}}$ is the $m \times m$ diagonal matrix with nonzero elements representing import-to-consumption ratio of each product. Therefore, the projected Use matrix of domestic transactions can be calculated by

$$\boldsymbol{U}^{*} = \boldsymbol{R} - \boldsymbol{P}^{*}. \qquad (3.12)$$

Competitive imports are removed from final demand. The initial final vector ($\boldsymbol{e} = [e_i]$) can be expressed as:

$$\boldsymbol{e} = \boldsymbol{f} + \boldsymbol{e}^{\boldsymbol{I}} \qquad (\mathbf{3.13})$$

where the vector $\boldsymbol{f} = [f_i]$ represents the final demand of domestic product i, and the vector $\boldsymbol{e^I} = [\boldsymbol{e_i^I}]$ denotes final demand supported by competitive imports. The final demand for domestic products can be estimated as follows:

$$\boldsymbol{f} = \boldsymbol{q} - \boldsymbol{I} - \boldsymbol{U}^* \quad (\mathbf{3.14})$$

where $\boldsymbol{q}$ denotes the vector of total product demands and $\boldsymbol{I}$ represents the vector of product imports. As a result, the leakage can be incorporated into the model.

3.2.2 Aggregation of IO Framework

The Canadian SUTs used in the thesis are provided by Statistics Canada at the detailed level with 524 products and 244 industries for the year 2017. The Canadian Supply and Use matrix have 492 product classes and 240 industry categories. Twelve products classes were deleted since they had no data. These included (1) cannabis products (except seeds, plants, and plant parts), (2) retail margins-cannabis products (licensed), (3) other used consumer goods, (4) subscriptions for online content, (5) computer equipment rental and leasing services, (6) office machinery and equipment (except computer equipment) rental and leasing services, (7) repair and maintenance, (8) operating supplies, (9) office supplies, (10) advertising, promotion, meals and entertainment, (11) travel, meetings and conventions, (12) transportation margins. Seven industry classes that have no data are also removed, comprising (1) cannabis stores (licensed), (2) repair and maintenance, (3) operating supplies, (4) office supplies, (5) advertising, promotion, meals and entertainment, (6) travel, meetings and conventions, (7) transportation margins.

Two product classes of gold and used motor vehicles were removed because these product categories relied completely on imports. After the aggregation, the Supply and Use matrices had dimensions of 478×233, i.e. they both comprise 478 commodities and 233 industries.

The initial six categories of primary inputs are aggregated into a category as total value added. Then an extended value-added matrix was derived that included three rows: (1) competitive imports, (2) net tax on products, and (3) total value added. This matrix will be part of the RAS rebalancing. Similarly, 277 classes of final demand are aggregated to total final demand. It should be noted that the aggregation of value added and final demand have no impact on the calculation of the model because the share of each input in total inputs is unchanged and final demand is fixed during the RAS procedure proposed by Malik et al. (2014).

3.2.3 Augmentation of SUTs

The augmentation approach is one common method to evaluate technical change in the IO framework (Rose 1984). It may be advantageous to simulate the impact of incorporating new commodities and sectors into an economy. The SUTs are first expanded in the base case scenario of an import substitution policy (Section 3.2.3.1) and then two additional scenarios are constructed and specify the augmentation process respectively, covering first-generation substitution policy (Section 3.2.3.2) and an advanced biofuel mandate (Section 3.2.3.3).

3.2.3.1 Base Case Scenario: Import Substitution Policy

The base-case scenario estimates the effect of replacing ethanol imports with domestic second-generation ethanol. The SUTs integrate two new commodities (i.e., second-generation ethanol and crop residues) and a new sector (i.e., the second-generation ethanol industry). Thus, the augmented SUTs have 480 commodities and 234 industrial sectors. The final demand vector has 480 entries while the value added matrix becomes a 3×234 matrix. After inserting additional rows and columns that represent the new sector and commodities, the model is ready to be rebalanced.

The sales of second-generation bioethanol are to take the place of all the reduced motor gasoline sales from ethanol imports. It should be noted that the motor gasoline commodity comprises fuel ethanol. The modification in the Use matrix of domestic transaction ($\boldsymbol{U} = [U_{ij}]$) and final demand vector of domestic products ($\boldsymbol{f} = [f_i]$) can be expressed as follows:

$$U^0_{ethanol,j} = \beta\, U^a_{gasoline,j}\,, \ \ \forall \text{j} \neq \text{ethanol} \qquad (3.15)$$

$$f^{0}_{ethanol} = \beta\, f^{a}_{gasoline} \tag{3.16}$$

where β represents the proportion of ethanol imports (E) to total domestic supply of motor gasoline class ($q_{gasoline}$). The superscript $\mathbf{0}$ denotes the matrix after augmentation that are ready for the RAS procedure. The superscript $\boldsymbol{a}$ represents the matrix before augmentation. The matrix $\boldsymbol{V} = [V_{ij}]$ represents the supply matrix and the second-generation ethanol is supplied by its own industry ($V^{0}_{ethanol,ethanol}$) and is set to be equal to the initial ethanol imports.

$$V^{0}_{ethanol,ethanol} = E \tag{3.17}$$

3.2.3.2 Scenario 1: First-Generation Substitution Policy

In this scenario, first-generation ethanol is replaced with second-generation ethanol. The augmented SUT framework is the same as that in base-case scenario, which incorporates two new commodities, i.e. second-generation ethanol and crop residues, and the new second-generation ethanol industrial sector. Suppose the production of first-generation ethanol decreases by W million dollars, which is substituted with domestic second-generation ethanol production. As a result, the sales of first-generation bioethanol are adjusted as follow:

$$U^{0}_{gasoline,\,j} = (1-\delta)\; U^{a}_{gasoline,\,j}, \forall \mathrm{j} \neq \text{ethanol} \tag{3.18}$$

$$f^{0}_{gasoline} = (1-\delta)\; f^{a}_{gasoline} \tag{3.19}$$

where δ represents the percentage of reduced first-generation ethanol (W) in total domestic supply of the commodity motor gasoline ($q_{gasoline}$). The superscripts $\boldsymbol{a}$ and $\mathbf{0}$ represent the matrix before and after augmentation, respectively. The domestic supply of first-generation ethanol reduces by \$$W$ million:

$$V^{0}_{gasoline,chemical} = V^{a}_{gasoline,chemical} - W \tag{3.20}$$

The reduced first-generation ethanol is assumed to be supplied by basic chemical manufacturing industry.

$$V^{0}_{ethanol,ethanol} = W \tag{3.21}$$

The second-generation ethanol is to replace the reduced demand of first-generation ethanol:

$$U^0_{ethanol,j} = \delta\, U^a_{gasoline,j}\,, \;\; \forall \text{j} \neq \text{ethanol} \qquad (3.22)$$

$$f^0_{ethanol} = \delta\, f^a_{gasoline} \qquad (3.23)$$

3.2.3.3 Scenario 2: Advanced Ethanol Mandate

The second scenario models are constructed to evaluate an advanced biofuel mandate. The modified IO model incorporates two new industries (second-generation ethanol and gasohol made from a mix of crop-residue-based ethanol fuel and gasoline). It also introduces three new commodities, i.e. crop residues, 2G ethanol and gasohol. The Supply and Use matrices are extended to 481 commodities and 235 industrial sectors. The final demand vector has 481 elements and the value-added matrix becomes 3-by-235 matrix.

To simulate the impact of a second-generation ethanol mandate, the following model was constructed. The first step of augmentation is to reduce domestic gasoline sales to final market and all industries except ethanol and gasohol sectors by percentage π.

$$U^0_{gasoline,\,j} = (1 - \pi)\; U^a_{gasoline,\,j}, \forall \text{j} \neq \text{ethanol, gasohol} \qquad (3.24)$$

$$f^0_{gasoline} = (1 - \pi)\; f^a_{gasoline} \qquad (3.25)$$

The superscript $\boldsymbol{a}$ denotes the pre-augmentation matrix whereas the superscript $\mathbf{0}$ represents augmented matrix ready for the RAS procedure.

Gasohol's sales are to replace all the reduced gasoline sales:

$$U^0_{gasohol,j} = \pi\, U^a_{gasoline,j}\,, \;\; \forall \text{j} \neq \text{ethanol, gasohol} \qquad (3.26)$$

$$f^0_{gasohol} = \pi\, f^a_{gasoline}. \qquad (3.27)$$

The supply of gasohol is set to substitute for π percent of the initial gasoline supply produced by the petroleum refineries industrial sector:

$$V^0_{gasohol,gasohol} = \pi V^a_{gasoline,gasoline}\,. \qquad (3.28)$$

In addition, the gasohol sector is constructed to be a mix of second-generation ethanol and gasoline with the assumption that the prices of ethanol fuel and gasoline are the same:

$$U^0_{ethanol,gasohol} = \alpha V^0_{gasohol,gasohol} \tag{3.29}$$

$$U^0_{gasoline,gasohol} = (1-\alpha) V^0_{gasohol,gasohol} \tag{3.30}$$

where the blending rate α denotes the proportion of second-generation ethanol in gasohol. Another underlying assumption is that the gasohol sector only serves as a mixer of these two commodities and does not have any other primary inputs.

The gasoline supply from the gasoline sector is reduced by the percentage $\pi\alpha$, since only $\pi\alpha$ percent of gasoline is replaced by the second-generation ethanol. Thus, the change in the Supply matrix is shown as follows.

$$V^0_{gasoline,gasoline} = (1-\pi\alpha)\, V^a_{gasoline,gaoline} \tag{3.31}$$

In each scenario, it is assumed that the ethanol is only produced by its own industrial sector and all consumed in the same year. Using this information, the capacity of the industrial sector can be estimated and the cost structure of the second-generation ethanol industrial sector can be made. The details are provided in Chapter 4. When the data is prepared, the intermediate inputs $U^0_{i,ethanol}$ and the primary inputs $v^0_{i,ethanol}$ of the second-generation ethanol industrial sector can be inserted, as estimated from the cost structure of the second-generation ethanol industry. After inserting new rows and columns with data into the initial SUTs, the matrices are re-balanced. The modified model could be reconciled by the RAS-type method.

3.2.4 Measuring Economic Output and Employment

In each scenario, the economic effect of construction of the second-generation plants is estimated before augmenting the SUTs.

This study has taken into consideration leakages out of the economy that are the result of international trade. For this reason, the leakages are integrated into the model when estimating the impact of constructing the second-generation plants:

$$\boldsymbol{\Delta x} = [\boldsymbol{I} - \boldsymbol{DB}]^{-1}\boldsymbol{D}\,\boldsymbol{\Delta g} \tag{3.32}$$

where $\boldsymbol{\Delta g}$ is a $m \times 1$ vector of the change in final demand without exports, reexports, imports, government production, and changes in inventories. It is noteworthy that the matrix of industry technology coefficients ($\boldsymbol{B}$) is derived from the Use matrix of domestic transaction ($\boldsymbol{U^0}$) in the modified model before augmentation while the market share matrix ($\boldsymbol{D}$) is calculated based on the supply matrix ($\boldsymbol{V^0}$) before augmentation.

Equation (3.32) can be further used for impact analysis after the RAS method. When the impact of further expansion of second-generation ethanol production is estimated, the matrix of industry technology coefficients ($\boldsymbol{B}$) is derived from the Use matrix of domestic transaction ($\boldsymbol{U^0}$) in the modified model after augmentation while the market share matrix ($\boldsymbol{D}$) is calculated based on the augmented supply matrix ($\boldsymbol{V^0}$). The direct effect of further expansion of second-generation ethanol is quantified by the initial change in final demand in corresponding scenarios.

The effect of second-generation ethanol production is also quantified using the modified RAS method that is depicted in Section 3.4. After that, the impacts on sectoral employment are estimated with a satellite account $\boldsymbol{Q}$. The change in employment (ΔQ_j) in industry j can be measured by the employment intensity q_j:

$$\boldsymbol{\Delta Q} = \boldsymbol{\hat{q}}\,\boldsymbol{\Delta x} \tag{3.33}$$

$$\Delta Q_j = q_j\,\Delta x_j \tag{3.33$'$}$$

where employment intensity q_j is assumed to be fixed and represents the employment per unit of total industrial sector output. We measure employment intensity q_i is estimated using the data in the base year (Statistics Canada 2021e).

GDP is calculated based on the income approach. Sectorial GDP is estimated using wages and salaries, employer's social contributions, gross mixed income, and gross operating surplus.

3.3 Basic RAS Method

The RAS method, also known as "biproportional" matrix balancing technique, was first proposed by Stone (1961). This method scales the rows and columns of the initial matrix to estimate a new matrix where prescribed row and column totals are respected (Bacharach 1970; Miller and Blair 2009; Temurshoev et al. 2011). In other words, the RAS procedure can update a matrix according to the new column and row totals and a fixed structure, which is called the constrained biproportional matrix problem (Polenske 1996). Since the RAS was originally introduced, it is recognized and employed to adjust or project national or regional input-output tables (IOTs) or supply and use table (SUTs) and to estimate the economic data as trade flows (Khan 1993; Lecomber 1969; Polenske 1996; Trinh and Phong 2013).

3.3.1 RAS Interpretation

The average RAS procedure is shown below (Khan 1993; Miller and Blair 2009; Trinh and Phong 2013). Besides the initial technical coefficient matrix $A_0 = [a_{ij}]$, RAS requires the following information for the target year: (1) the vector of gross output (x^*); (2) vector of total intermediate sales (u^*), and purchases (v^*). Then, the RAS operates as

$$A^* = \hat{r} A_0 \hat{s} = \hat{r}_n \hat{r}_{n-1} \cdots \hat{r}_1 \, A_0 \, \hat{s}_1 \, \hat{s}_2 \cdots \, \hat{s}_n \tag{3.34}$$

$$\hat{r}_i = \hat{u}_i^{-1} \hat{u}^* \tag{3.35}$$

$$\hat{s}_i = \hat{v}_i^{-1} \hat{v}^* \tag{3.36}$$

where A^* is the predicted matrix, $\hat{r}$ is the row multipliers, $\hat{s}$ is the column multipliers, u_i and v_i are vectors of column totals and row totals of round i time, respectively. A hat over a vector indicates the vector has been diagonalized to be a matrix. Finally, after a certain number of iterations (n), the results might converge and a unique solution of the technical coefficient matrix is achieved.

The iterative procedure for the constrained biproportional-matrix problem is identical to solving a system of linear equations simultaneously (Polenske 1996; Bacharach 1970). In fact, the RAS method solves the constrained minimum information distance problem. The specific constrained optimization problem is to derive a new coefficient matrix (A^*) that varies the least compared to initial matrix (A_0) subject to given row and column totals. The underlying assumption of this method is that A_0 is still the best representation of interindustry relationships without any new information (Miller and Blair, 2009).

Although the RAS technique is criticized for the randomness of row and column multipliers, these multipliers have a logical economic basis. Each coefficient a_{ij} in A_0 is subject to the substitution effect ($\hat{r}$) and the fabrication effect ($\hat{s}$) which reflect uniform changes across each row or column respectively (Stone 1961). The substitution effect is quantified by the degree in which the output of the i^{th} sector has been used as a substitute for another sectoral output during intermediate production. This effect may be largely caused by relative price changes (Parikh 1979). The fabrication effect is measured as an adjusted percentage of primary inputs in total industrial sector inputs (Miller and Blair 2009).

Other researchers further developed the rationale of the RAS method. For example, Toh (1998) interpreted the substitution and fabrication factors as estimates derived from an instrumental variable method and therefore calculated their asymptotic standard errors and relative accuracy of projected technical coefficients. Toh (1998) constructed an adjustment cost minimization model that showed the process of choosing substitution and fabrication factors in industrial sector. The associated Lagrangian multipliers can denote marginal cost and be used to evaluate structural constraints and structural change.

3.3.2 RAS Variants

Numerous variations of the RAS technique followed the original one (Miller and Blair 2009; Malik et al. 2014). Among them are the well-known generalized methods named GRAS and KRAS. These two methods relax previous assumptions and are useful in more empirical application. Other variants of RAS include TRAS (Gilchrist and St. Louis, 2010, three-stage RAS), CRAS (Minguez et al., 2009, Cell-corrected RAS)., ERAS (Israilevich, 1986, “extended” RAS), etc.

The GRAS method (Günlük-Şenesen and Bates 1988; Junius and Oosterhaven 2003) was developed to deal with the problem of the matrix having negative entries. This variant relaxes an implicit assumption in the previous RAS method that the initial matrices (A_0) only have non-negative elements, which restricts its applicability to IOTs and SUTs with negative elements (e.g., in the trade and transport margin or final demand matrices) (Temurshoev et al. 2011). However, GRAS still assumes each row and column of the initial matrix has at least one positive element. For this reason, Temurshoev et al. (2013) extended the GRAS to include matrices in which at least one row or column consist only of nonpositive numbers.

Similarly, the KRAS method (Lenzen et al. 2009) is a further generalization of the GRAS method. This method can manage conflicting exogenous information (Gallego and Lenzen 2009). It also extends the GRAS to restrict any subset of matrices and allows for non-unity coefficients (Temurshoev et al. 2011). The KRAS technique is identical to the GRAS technique where reliability weights are assigned one and constraint coefficients are 1 or -1 (Valderas-Jaramillo et al. 2019).

The RAS-type methods above may be applied to both IOTs and SUTs theoretically, but their applications to SUTs remains challenging. As a result, certain variants are introduced for studies based on SUTs. For example, as a particular case of the GRAS approach, the SUT–RAS method (Temurshoev and Timmer 2011) is proposed to project integrated SUTs if target product outputs are not available. Valderas-Jaramillo et al. (2019) further developed a new variant SUT-RAS method with endogenous industry output and compared it to adapted Euro (SUT-Euro) with comparable or even identical exogenous information. They came to the conclusion that the SUT-RAS technique should be utilized if target industrial outputs were known, whereas the SUT-Euro technique should be preferred otherwise.

Different variants can be modified to incorporate exogenous information into corresponding rows, columns, or individual cells of the updated matrix (Miller and Blair 2009; Parikh 1979). Since the updated matrix estimated by the RAS method is as close to the initial one as possible, the simple RAS cannot achieve an accurate estimate of an IOTs or SUTs when the economy experiences significant structural change, technological change, or considerable change in relative price (Eurostat, 2008). For that reason, extra information (e.g., survey data and expert opinion) might facilitate capturing the changes between the initial matrix and the updated matrix and help the estimated matrix more closely reflect the actual matrix. In fact, Miller and Blair (2009) summarized that accurate exogenous information helps RAS improve the precision of the projection in general. This is confirmed by research (Paelnick and Waelbroeck, 1963; Barker 1975; Allen and Lecomber, 1975; Parikh 1979; Eurostat 2008). The hybrid strategy has been widely used to generate annual IOTs for non-benchmark-table years (Miller and Blair 2009).

3.3.3 RAS Application

The RAS method is widely used to balance or estimate the IOTs and SUTs. The non-survey methods (or partial-survey with exogenous information) for IOTs or SUTs are also driven by timeliness, consistency, and regionalization (Temurshoev et al. 2011; Valderas-Jaramillo et al. 2019). When SUTs were analyzed, early studies focused on projections and regionalization of SUTs (Beutel 2008; Dalgaard and Gysting 2004; Gallego and Lenzen 2009; Jackson 1998; Lahr 2001a; Timmer et al. 2005).

It is noteworthy that the RAS method has been used to estimate the effect of technological change. The RAS method can be applied to reconcile the augmented IOTs with new rows and columns. For example, Li et al. (2012b) utilized the RAS to rebalance the 2009 Chinese IOTs that incorporated a major wind energy industry. Liu et al. (2012) also augmented the 2006 IOTs for Taiwan with 11 sectors and utilized the KRAS method to reconcile the tables. In addition, the RAS method is employed to analyze technological change in the IOTs with individual cells revised (Andreosso-O'Callaghan and Yue 2000; Dietzenbacher and Hoekstra 2002; Dobrescu and Gaftea 2012; Van der Linden and Dietzenbacher 1995, 2000).

On the other hand, SUTs have a more complex setup for reconciliation than IOTs with marginal totals. SUTs may not have explicit constraints to match (e.g., total industry output) but instead have implicit constraints. Some constraints may be in the form of implicit ratios within the system (e.g., tax rates on final consumption), which must be linearized. Given the complex relationships and the implicit constraints, redundant and even contradicting restrictions may emerge (Stanger 2018).

Malik et al. (2014) developed a modified RAS method to rebalance the national SUTs to assess the impact of a new alcohol industry in Australia. This method will be specified and extended for analysis in this study in Section 3.4.

3.3.4 Performance of RAS

Some researchers have evaluated the performance of the RAS and alternative methods for IOTs projection (Harrigan et al. 1980; Khan 1993; Lamonica et al. 2020; Lecomber 1975; McDougall 1999; Polenske 1996), while others compare the performance of the common method for SUTs adjustment (Temurshoev et al. 2011; Valderas-Jaramillo et al. 2019). The results showed that the RAS method was advantageous for IOTs (and even SUTs) projection and adjustment.

First, the RAS method generally provides more accurate estimates than the other methods with a relatively minimal amount of information and low cost (Huang et al., 2008; Temurshoev et al., 2011). When the row and column margins of the estimated matrix are available, the (G)RAS method provides better estimates; if industrial sector output for the projected matrix are available but commodity outputs are not, SUT-RAS method is preferred.

Table 3.1 Performance of RAS-Type Methods with Certain Information

	x_t	q_t	u_t	v_t	m_t	**Method with best performance**
Information available	×	×	×	×	×	GRAS (Temurshoev et al. 2011)
	×		×	×	×	SUT-RAS (Valderas-Jaramillo et al. 2019)
			×	×	×	SUT-EURO (Valderas-Jaramillo et al. 2019)

As a bi-proportional method, the RAS-type method derives more accurate results than the alternative one-sided updating method when the prescribed information of the

RAS is available. Examples of one-sided approaches are the Statistical Correction Method (Eurostat 2008; Tilanus 1968), the EUKLEMS method (Timmer et al. 2005), and the Proportional Correction Method (Eurostat 2008). The reason for this is that not all available information is utilized, so random adjustments may exist during the process, leading to less robust results (Temurshoev et al. 2011; Temurshoev and Timmer 2011; Valderas-Jaramillo et al. 2019). Moreover, Temurshoev et al. (2011) suggested that the (G)RAS performed better in comparison with the Euro methods (Beutel 2002; Eurostat 2008) and other widely used approaches. Nonetheless, if industrial sector outputs are unknown, the SUT-EURO (Beutel 2008) may outperform the other common methods (Valderas-Jaramillo et al. 2019). The summary in Table 3.1 is based on the previous literature, more extensive comparative evaluation of these methods is still needed.

Second, the RAS method allows for economically meaningful interpretation (Stone 1961; Temurshoev et al. 2013; Toh 1998; van der Linden and Dietzenbacher 2000). Its row and column multipliers ($\hat{r}$ and $\hat{s}$) can explain total changes and stepwise changes in the procedure at the same time.

Third, the iterative algorithm of the RAS is easier to apply with Excel or R as compared with the high-performance solver, and the row and column multipliers and target matrix are directly derived from the iterative method (Polenske 1996; Temurshoev et al. 2013). The simple procedure facilitates controlling the convergence of the iterative process as compared to the average optimization solvers especially when the problem is about to be infeasible for the RAS (Temurshoev et al. 2013).

The RAS-type method has its limitations. In the first place, even though the RAS technique has been shown to be more effective than other techniques, it can lead to considerable errors of estimation with certain unrealistic forecasts (Polenske 1996). The accuracy of the estimation might be improved if great quantities of high-quality data and real structural change are incorporated in advance (Parikh 1979; Polenske 1996). Also, even though individual elements might be badly estimated, total intermediate demands by sectors tend to be more precisely estimated (Miller and Blair 2009; Parikh

1979).

In addition, the iteration process may not converge in certain instances (Miller and Blair 2009; Polenske 1996). One of the most relevant reasons may be a sparse initial matrix with numerous zeros (e.g., a disaggregated transactions matrix with hundreds of sectors), so the remaining nonzero elements can hardly afford the entire burden of change (Miller and Blair 2009). A straightforward solution is to assign a small positive number to zero-valued cells in the base matrix (Hewings 1969; de Mesnard 2003).

The RAS technique has been criticized for adjusting input coefficients arbitrary against technological change as well as market forces (Eurostat 2008; Temursho 2021). The enforcement of consistency is given priority in the updating procedure. Indeed, innovation, technological trends, and market forces should be incorporated into the procedure (Eurostat 2008). For example, innovative industries should see an increase in relative importance across all activities and fading industries vice versa.

3.4 Modified RAS technique

In this subsection, the modified RAS method (Malik et al. 2014) is introduced and further adapted to the rectangular SUTs in the analysis. After inserting new rows and columns with new data, the SUTs are unbalanced. To reconcile the SUTs, this RAS-type method was chosen because it provides an outcome for the economy after introduction of second-generation ethanol but also depicts the changes step by step. The RAS-type method proposed by Malik et al. (2014) assumes that the production function of each industry and market share of each commodity remains the same. It is noteworthy that both the industry technology matrix and the market shares matrix remains the same during this procedure. Thus, it focuses on the fabrication effect rather than the substitution effect. The assumption of minimal substitution effect may be partly explained by the small relative price change or perfect inelasticity of supply.

It is noteworthy that the imports had been deducted from the total product demand ($\boldsymbol{q^d}$) and supply ($\boldsymbol{q^s}$) before this procedure is applied. It means the two variables in the analysis do not include imports. The variable with subscript $\mathbf{0}$ indicates that it has experienced augmentation and is ready for the RAS procedure.

In the first iteration, the supply and demand of commodities are first rebalanced. To be specific, we first calculate the vector of total product demand ($\boldsymbol{q_0^d}$) according to the adjusted use matrix without competitive imports ($\boldsymbol{U_0}$) and adjusted final demand vector from domestic products ($\boldsymbol{f_0}$).

$$\boldsymbol{q_0^d} = \boldsymbol{U_0}\, \boldsymbol{i_n} + \boldsymbol{f_0} \tag{3.37}$$

The vector $\boldsymbol{i_n}$ is a n-sized row summation operator where n is the column dimension of modified Use matrix. We also compute the vector of total product supply ($\boldsymbol{q_0^s}$) according to the row total of supply matrix ($\boldsymbol{V} = [V_{ij}]$):

$$\boldsymbol{q_0^s} = \boldsymbol{V_0}\, \boldsymbol{i_n}. \tag{3.38}$$

Then total products supply is scaled with the RAS multipliers:

$$\boldsymbol{V_1} = [\boldsymbol{\hat{q}_0^s}]^{-1}\boldsymbol{\hat{q}_0^d}\boldsymbol{V_0} \tag{3.39}$$

$$V_{ij}^1 = V_{ij}^0 \frac{q_i^d}{q_i^s} \tag{3.39'}$$

All the subscript **1** denote the variables in the round 1 time. Thereafter, total supply of commodities is equal to its demand, but industry costs and revenues remain unbalanced.

The reconciliation of industry inputs and outputs follows. The total inputs of the industrial sectors are calculated by summing up the column totals of the modified use matrix ($\boldsymbol{U_0}$) and the extended value-added matrix augmented with competitive imports ($\boldsymbol{v_0}$):

$$\boldsymbol{x_1^{in}} = \boldsymbol{U_0^T}\, \boldsymbol{i_m} + \boldsymbol{v_0^T}\boldsymbol{i_s} \tag{3.40}$$

where $\boldsymbol{i_m}$ and $\boldsymbol{i_s}$ is a m- and s-sized row summation operator. The total industrial sector outputs are estimated according to the column totals of the supply matrix:

$$\boldsymbol{x_1^{out}} = \boldsymbol{V_1^T}\boldsymbol{i_m} \tag{3.41}$$

Then the domestic intermediate inputs of each industrial sector are adjusted according to the ratio of its industrial sector output to industry input:

$$\boldsymbol{U_1} = \boldsymbol{U_0}\left[\boldsymbol{\hat{x}_t^{in}}\right]^{-1}\boldsymbol{\hat{x}_t^{out}}, \tag{3.42}$$

$$U_{ij}^{1} = U_{ij}^{0}\,\frac{x_j^{out}}{x_j^{in}}. \tag{3.43'}$$

Similarly, primary inputs of each industry are adjusted by the same scaler:

$$\boldsymbol{v_1} = \boldsymbol{v_0}\left[\,\widehat{\boldsymbol{x}}_{\boldsymbol{t}}^{\boldsymbol{in}}\,\right]^{-1}\widehat{\boldsymbol{x}}_{\boldsymbol{t}}^{\boldsymbol{out}} \tag{3.43}$$

$$v_{ij}^{1} = v_{ij}^{0}\,\frac{x_j^{out}}{x_j^{in}} \tag{3.43'}$$

After that, cost and revenue of each industrial sector are balanced. Nonetheless, product demand and supply are not equal. The algorithm returns to Equation (3.37) and begins the next round. It is noteworthy that the adjusted final demand vector $(\boldsymbol{f})$ remains the same during the entire RAS procedure.

The modified RAS procedure can be expressed as a compact statement. Suppose $\boldsymbol{A_t} = \begin{bmatrix} \boldsymbol{O} & \overline{\boldsymbol{U}}_{\boldsymbol{t}} \\ \boldsymbol{V_t} & \boldsymbol{O} \end{bmatrix}$, $\overline{\boldsymbol{U}}_{\boldsymbol{t}} = \begin{bmatrix} \boldsymbol{U_t} \\ \boldsymbol{v_t} \end{bmatrix}$. The round t are taken from 1 to n where n represent the number of iterations to reach the convergence. The RAS operates as:

$$\boldsymbol{A}^{*} = \widehat{\boldsymbol{R}}\boldsymbol{A_0}\widehat{\boldsymbol{S}} = \widehat{\boldsymbol{R}}_{\boldsymbol{n}}\widehat{\boldsymbol{R}}_{\boldsymbol{n-1}}\cdots\widehat{\boldsymbol{R}}_{\boldsymbol{1}}\boldsymbol{A_0}\,\widehat{\boldsymbol{S}}_{\boldsymbol{1}}\,\widehat{\boldsymbol{S}}_{\boldsymbol{2}}\cdots\,\widehat{\boldsymbol{S}}_{\boldsymbol{n}} \tag{3.44}$$

where $\boldsymbol{A}^{*}$ is the updated matrix, and $\widehat{\boldsymbol{R}}$ and $\widehat{\boldsymbol{S}}$ are the row multipliers and column multipliers. To be specific, the matrices $\widehat{\boldsymbol{R}}_{\boldsymbol{t}} = \begin{bmatrix} \boldsymbol{I_m} & \boldsymbol{O} \\ \boldsymbol{O} & \widehat{\boldsymbol{r}}_{\boldsymbol{t}} \end{bmatrix}$ and $\widehat{\boldsymbol{S}}_{\boldsymbol{t}} = \begin{bmatrix} \boldsymbol{I_n} & \boldsymbol{O} \\ \boldsymbol{O} & \widehat{\boldsymbol{s}}_{\boldsymbol{t}} \end{bmatrix}$ represent the scalers of round $\boldsymbol{t}$ time. The matrices of $\boldsymbol{I_m}$ and $\boldsymbol{I_n}$ are identity matrices of size m and n, respectively. The matrices $\widehat{\boldsymbol{r}}_{\boldsymbol{t}}$ and $\widehat{\boldsymbol{s}}_{\boldsymbol{t}}$ are set according to:

$$\widehat{\boldsymbol{r}}_{\boldsymbol{t}} = [\,\widehat{\boldsymbol{q}}_{\boldsymbol{t}}^{\boldsymbol{s}}\,]^{-1}\widehat{\boldsymbol{q}}_{\boldsymbol{t}}^{\boldsymbol{d}}, \tag{3.45}$$

$$\widehat{\boldsymbol{s}}_{\boldsymbol{t}} = \left[\,\widehat{\boldsymbol{x}}_{\boldsymbol{t}}^{\boldsymbol{in}}\,\right]^{-1}\widehat{\boldsymbol{x}}_{\boldsymbol{t}}^{\boldsymbol{out}}. \tag{3.46}$$

The vector of $\boldsymbol{q_t^s}$ is the row total vector of $\boldsymbol{V_t}$ while $\boldsymbol{x_t^{out}}$ is the column total vector of $\boldsymbol{V_t}$, respectively. The vector of $\boldsymbol{x_t^{in}}$ is the column total vector of $\overline{\boldsymbol{U}}_{\boldsymbol{t}}$ whereas the vector of $\boldsymbol{q_t^d}$ is the row total vector of $\boldsymbol{U_t}$. Finally, after a certain number of iterations (n), the results should converge.

The procedure provides both final state of the economy and traces the path of the economy during the technological change. The updated supply and use matrices $\boldsymbol{V}^{*}$ and $\boldsymbol{U}^{*}$ are taken from the update matrix $\boldsymbol{A}^{*}$ and the balanced industrial sector output can be achieved by either $\boldsymbol{x_n^{in}}$ or $\boldsymbol{x_n^{out}}$ in the final round (n).

3.5 Summary

In the analysis, the thesis first expands the Canadian SUTs with new rows and columns to estimate the macroeconomic effect of a new biofuel. With this change, the SUTs become unbalanced. A modified RAS method (RAS-M) proposed by Malik et al. (2014) was used to rebalance the SUTs. This method is designed for SUTs adjustment after augmentation and provides the greatest accuracy in the RAS family. It is noteworthy that the RAS-M method assumes that the production function of each industrial sector is unchanged. It implies that the substitution effect, mainly driven by price changes, does not exist. This case might be explained by inelastic demand or trivial price change. Thus, this modified method focusses on the fabrication effect caused by technological change.

It is interesting that SUTs projection for technical change is similar to the SUTs projection without the information about the commodity outputs and industrial sector outputs in the target year. Thus, the relevant methods cover endo-SUT-RAS and endo-SUT-Euro (Valderas-Jaramillo et al., 2019). From the available literature above, the endo-SUT-Euro performs better in this case. However, estimated SUTs derived from the Euro family are dependent on growth rates of macroeconomic measures which are hard to define in the SUTs rebalancing (Temurshoev et al., 2011). The better performance of the SUT-Euro method as compared to the exo-SUT-RAS might be on account of certain assumptions, for example, constant market shares in short-term estimation (Valderas-Jaramillo et al., 2021). On the other hand, although the endo-SUT-RAS method can trace the substitution effect, the value added are assumed to be fixed during the SUTs adjustment. This assumption is in conflict with the target of estimating the macroeconomic effect (i.e., economic output or employment consequence) driven by new industry.

Chapter 4: Data Preparation of the Biofuel Sector in the SUTs

In this chapter, data on the crop residue commodity is provided, including the sustainable amount of wheat and corn residue, and the estimate of crop residues used for livestock, and biofuel (Section 4.1). The data for the second-generation ethanol plant is summarized in Section 4.2. Ethanol price is estimated according to its margin value matrix and is found in Section 4.3.

Specific data for the base-case scenario and three extended policy scenarios are also presented. In the base-case scenario, current ethanol imports are all replaced by domestic second-generation ethanol (Section 4.4). In the first scenario, 50 percent of first-generation ethanol is replaced by second-generation ethanol (Section 4.5). The second scenario implements an advanced ethanol mandate (Section 4.6). In this scenario, the model specially is extended to include a gasohol commodity as well as gasohol industrial sector. The gasohol commodity is a mix of 10 percent second-generation ethanol and 90 percent gasoline and the gasohol is assumed to replace 20 percent of the existing gasoline demand. In every scenario, we trace the data preparation for the biofuel industries as well as the related new commodities. The study describes how the statistics are entered into the Canadian SUTs. This highlights the cost structure of the second-generation ethanol production. In Section 4.7, the data for the GHG emission estimates is used in each scenario.

Since second-generation ethanol from agricultural residues has not been commercialized in Canada, these scenarios are all hypothetical. It is also noteworthy that two separate shocks exist for each scenario. One shock is the construction of the second-generation ethanol plant, while the other shock is the operation of the second-generation to produce the commodity. The two shocks are separated because the investment tends to be prior to the production and is a one-time investment in the short to medium run. For example, the investment may happen one year prior to the production.

The study applies the Canadian supply and use tables at basic prices. The class of motor gasoline in the Canadian Supply-Use Tables incorporates motor gasoline blends as well as fuel ethanol. Considering that almost all the ethanol fuel is from first-generation feedstock in Canada, the ethanol fuel included in motor gasoline in 2017 can be regarded as first-generation ethanol.

4.1 Data Preparation of Crop Residues

In the analysis, the feedstock for the second-generation ethanol industrial sector is crop residues (e.g., corn residues). In this subsection, the potential crop residues in Canada are introduced, especially wheat straw and corn stover (Section 4.1.1). Then, data preparation of the crop residues in the SUTs is described (Section 4.1.2).

4.1.1 Canadian Sustainable Production of Crop Residues

Sustainable collection of agricultural residues is significant. Although crop residues left in the field may benefit the environment, particularly soil and microbes, excessive waste may negatively influence soil warming in the planting season, machinery operation, and GHG savings (Oo and Lalonde 2012). Between 2001 and 2010, the total accessible crop residue sustainably removed from land was 54.75 million metric ton (MT) in Canada (Li et al. 2012a). Among them, 47.90 million MT was estimated to be for ethanol feedstock. Considering the conversion rate of 270 liters per metric ton (Mabee and Saddler 2010), it implies 12.95 billion liters of ethanol was produced.

Wheat straw and corn residue are the dominant crop residues in Canada. In 2017, total production of wheat was 30.38 million MT and the total harvest area was 22.20 million acres. The production of corn for grain in 2017 was 14.10 million MT and the production of corn for silage in 2017 was 13.27 million MT. The harvested area of corn for grain was 3.47 million acres, while harvested area of corn for silage in 2017 was 0.73 million acres (Statistics Canada 2021c). The corn for grain provides the second-largest crop residues in Canada. The residue to grain ratio of wheat is 1.3 and that of corn is 1.0 (Pandiyan et al. 2019).

The required residues to maintain 3.4% Soil Organic Carbon (SOC) is 3.88 MT per acre. Sustainable harvestable residues of grain corn and wheat were estimated to be 2.07 and 1.76 MT per acre, respectively (Oo and Lalonde 2012). Thus, the total sustainable grain corn residues were 7.18 million MT, while the total sustainable wheat residues were 39.07 million MT in 2017. More details of Canadian main crop residues are shown in Table 4.1.

Table 4.1 Canadian Main Crop Residues in 2017

	Production (million MT)	Residue to grain ratio	Harvest area (million acres)	Sustainable residues harvest (tonne/acre)	Total sustainable residues (million MT)
Wheat	30.38	1.3	22.20	1.76	39.07
Corn for grain	14.10	1	3.47	2.07	7.18

4.1.2 Data Preparation of Crop Residues

Given its availability, a small amount of straw can be used for animal feeding. However, a higher share of straw in a feed ration may have a negative impact on its nutrient content as well as cattle intake. For example, the optimal amount of straw in a ration for dairy cows would be 0.25-0.5 kg $head^{-1}$ day^{-1} (kg h^{-1} d^{-1}) (Li et al. 2012a). Given Canada has high annual production of tame hay (25.8 million MT) and fodder corn (7.8 million MT) for animal feeding, crop straw used for animal feeding is minimal (Li et al. 2012a). On the other hand, wheat straw harvested in the regions with a large cattle sector are mainly collected for cattle bedding. In the areas with a moderate cattle industry, cereal straws have not been sustainably utilized (Oo and Lalonde 2012). That is why stubble burning used to be a common in the prairie provinces which is now restricted. The redundant residues have enabled other uses such as biofuel.

Following the method of Li et al. (2012a), the amount of crop residues used for feeding and bedding by livestock in 2017 was estimated, as recorded in Table 4.2. The total crop residues used by livestock were estimated to be 5.81 million MT.

Table 4.2 Crop Residue Used by Livestock in 2017[2]

Livestock	**Head** (thousand)	**Feeding Used** (million MT)	**Bedding Used** (million MT)	**Total Crop Residues** (million MT)
Cattle	12,535	1.88	2.51	4.39
Pig	14,200	-	1.42	1.42
Total	-	1.88	3.93	5.81

Source: Statistics Canada 2017; 2021f; 2021g

In the detailed-level SUTs, the product class of imputed feed (animal feed produced for own consumption) includes crop residues used for livestock feeding. Then the new commodity of crop residues will only incorporate crop residues used for livestock bedding. The crop residues utilized for livestock bedding ($S_{residue}$) are 3.93 million MT. The cost of crop residue in the animal production sector is projected to be $31.7 per MT in 2018 Canadian dollar (Wang et al., 2020a). Therefore, crop residues purchased by animal production in 2017 is estimated to be $122.14 million using a 2% annual inflation rate.

$$U^P_{residues,animal} = P^P_{residues} S_{residue} = 31.08 \times 3.93 = 122.14 \tag{4.1}$$

As illustrated in Table 4.3, the value at purchaser price into basic price was converted according to the grain margin value matrix. The crop residues used in the animal production industry at basic price was $93.60 million.

$$U^B_{residues,animal} = U^P_{residues,animal} \frac{q^B_{residues}}{q^P_{residues}} = U^P_{residues,animal} \frac{q^B_{grain}}{q^P_{grain}} \tag{4.2}$$

$$= 122.14 \times \frac{4277.56}{5581.76} = 93.60$$

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[2] Crop residue used by livestock = Cattle feeding** + Cattle bedding*** + Pig bedding****.

**Cattle feeding used = number of cattle (h) × 1 kg h^{-1} d^{-1} × 150 d.

***Cattle bedding used = number of cattle (h) × 2 kg h^{-1} d^{-1}× 100 d.

****Pig bedding used = number of pig (p) × 1 kg h^{-1} d^{-1} × 100 d.

The variables $q^B_{residue}$ and $q^P_{residue}$ represent total crop residues used at basic prices and purchaser prices, respectively, while q^B_{grain} and q^P_{grain} denote total grain (except wheat) used at the basic prices and purchaser prices, respectively. The underlying assumption is that the margin matrix of crop residues is the same as that of the grains commodity (except wheat).

Table 4.3 Margin Value Matrix for Crop Residue Used in Animal Production

crop residue at basic price	93.60
Wholesale margins - farm products	12.19
Rail freight transportation services	6.09
Water freight transportation services	0.04
Road transportation services for specialized freight	6.45
Water transportation support, maintenance and repair services	0.03
Road transportation support services	0.04
Freight transportation arrangement and customs brokering services	0.23
Other transportation support services	0.04
Grain storage	3.43

The focus in this study is on corn residues since corn-stover-based ethanol plants are used in the following analysis. No specific data were focused on the use of corn residues for animal bedding. Only the total use for animal bedding was estimated. Therefore, crop residues available for ethanol production are between 3.26 and 7.18 million MT. Based on the available technology, the conversion rate is 235.62 L/MT. It implies that corn residues have the potential of producing 767.16 -1692.45 million liters of second-generation ethanol. Considering transportation cost, this data might be overestimated. However, this technology is readily adapted to different feedstocks. Therefore, the analysis shows the potential use of various crop residues.

Corn is grown mainly in Ontario and Quebec. The production of corn for grain is 3.78 million MT (26.81% of Canada's corn) and 8.77 million MT (66.08% of Canada's corn) in Quebec and Ontario, respectively. In Ontario, crop straw yields are quite high but underutilized (Li et al. 2012a; Hewson 2010; Oo and Lalonde 2012). For example, grain corn land becomes significantly denser with more biomass over time. It exacerbates the management concern of grain corn residues since it is difficult to decompose. Farmers tend to sell excessive grain corn residues (Oo and Lalonde 2012). Therefore, theses corn residues are expected to be utilized to produce second-generation ethanol.

4.2 Data Preparation of Target 2G Ethanol Plant

Second-generation ethanol production from agricultural residues has not been commercialized in Canada. This study assumes that all of the second-generation ethanol plants planned for Canada use the latent technology described in the report of Petrides (2020). The typical plant in Petrides's report is set as a benchmark for a second-generation ethanol industry. With the assumption of constant returns to scale, this study calculates the number of plants needed to meet the demand for second-generation ethanol and construct the revenue and cost structure of the industrial sector in the base case scenario (Section 4.4) and extended scenarios (Section 4.5 and 4.6).

The second-generation plant in this study was developed by SuperPro Designer® (Intelligen, Inc.). Its process uses the NREL thermochemical bioethanol technology and is widely used in practice (Petrides 2020). For example, Mupondwa et.al (2017) designed a production process using SuperPro Designer® (Intelligen, Inc.) and applied it to a large-scale ethanol facility for wheat straw in the Canadian Prairies (Saskatchewan). However, the available data for the wheat-straw-based plant is not enough to simulate the economy. For this reason, Petrides's report to use corn residues as the feedstock was used. In addition, the US data for the year 2013 that was used in the report was adjusted to 2017 Canadian dollars using a 2% annual inflation rate and 1.03 average exchange rate for 2013 (OzForex Ltd 2021).

Capital investment for the plant was estimated to be $168.90 million in 2017 (Petrides 2020). Thus, the cost of building the plants was $168.90 million. This technology is relatively inexpensive compared to alternative cellulosic ethanol technologies. In fact, second-generation biofuel refineries need substantial capital investment, over five times the cost of comparable bioethanol refineries from starch

(Carriquiry et al. 2011). For example, commercial cellulosic refineries operating in the US cost between $200 to $275 million U.S. dollar (Campbell et al. 2018). Capital expenditure per liter of ethanol for the DuPont cellulosic ethanol refinery in Iowa (which has been sold to Verbio) was around US$1.98 L^{-1} (Hirtzner and Renshaw 2017). The capital cost for first-generation ethanol production was estimated to be far lower, US$0.33 L^{-1} in the US and $0.60-0.95 L^{-1} in Canada (Coad and Bristow 2011).

To estimate the impact of constructing a second-generation ethanol plant, the cost structure of capital expenditure for the plant is built based on the data from Gonzalez et al. (2011). The cost structure of building a cellulosic ethanol plant is shown in Table 4.4.

Table 4.4 Cost Structure of Building 2G Ethanol Plant in 2017

Inputs	Share (%)
Industrial buildings (except mine buildings)	5.18%
Waterworks engineering works	0.47%
Sewage engineering works	0.70%
Material handling equipment	5.71%
Other industry-specific machinery	50.61%
Heating and cooling equipment (except household refrigerators and freezers)	9.14%
Other engine and power transmission equipment	19.14%
Turbines, turbine generators, and turbine generator sets (except aircraft turbines)	9.04%

Besides capital cost, major cost components of cellulosic ethanol refineries include feedstock costs and operating costs to maintain ethanol refineries. The costs of corn stover accounts for 33.29% of total production costs in Pretrides's case. According to Carriquiry et al. (2011), second-generation feedstock costs represented between 32–52 percent of the total cost of biofuel production in the US. The purchaser price of crop residue was estimated to be $50-90/ton (Gebreslassie et al. 2012; Osmani and Zhang 2017). The price of corn stover used here is in this price range. Second-generation ethanol is produced at a rate of 235.62 liter per tonne of corn stover.

The average operating costs include energy, chemicals, enzymes, waste disposal, as well as fixed costs like labor, service, and tax (Wang et al. 2020a). The primary operating costs of this plant are facility-dependent cost and hydrolase, composing 24.14% and 21.51% of the total production costs, respectively. The cost structure of operating the target plant is shown in Table 4.5.

Table 4.5 Cost Structure of Operating 2G Ethanol Plant in 2017

Inputs	Annual amount	Cost at purchaser price (M$)
Corn stover	749,074 MT	41.76
RO Water	1,519,697 MT	8.47
Water	1,334,350 MT	0.74
Std Power	50,474,110 kW-h	2.81
Cooling Water	95,898,775 MT	5.34
Well Water	1,367,056 MT	0.15
Facility-dependent cost	N.A.	30.28
Amm. Sulfate	650,426 kg	0.073
Hydrolase	2,122,874 kg	26.98
Labor-dependent cost	N.A.	4.04
Waste treatment/disposal	-	0.71
Other operating surplus	-	0.027
Total cost	-	125.44

Source: Petrides 2020

The annual production of cellulosic ethanol was 176.50 million liters for this plant. Huang et al. (2009) indicated that operating capacity might be around 245 million liters, while Wright and Brown (2007b) suggested a much higher potential (1.35 billion liters) compared to 450 million liters for grain ethanol. In addition, the plant also produces electricity as a byproduct. Table 4.6 presents the revenue structure of the plant.

Table 4.6 Total Revenue of 2G Ethanol Plant in 2017

Outputs	Annual amount	Selling price	Revenue (M$)
Ethanol	176,498,856 L	0.74 $/L	129.97
Electricity	53,047,114 kW-h	0.05575 $/kW-h	2.96
Total	-	-	132.93

Source: Petrides 2020

This plant is assumed to provide a benchmark for the second-generation ethanol industry in Canada. The total revenue of the second-generation ethanol industry includes its ethanol and electricity sales. To construct the revenue and cost structure of the crop-residue-based ethanol sector, the study further assumes that this industry is composed by N plants with the same cost and revenue structure as that of the target plant. This involves the assumption of constant returns to scale.

4.3 Ethanol Price

In this subsection, Canadian ethanol price in 2017 is estimated, as indicated in Table 4.7. The retail price of ethanol ($P^{R}_{ethanol}$) is set to be equivalent to the average monthly retail price of gasoline ($1.12 L^{-1}) in 2017.

Table 4.7 Retail Price of Gasoline in 2017 (cent/liter)

Jan.	Feb.	Mar.	April.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average
112.2	106.5	106	116.1	110.9	106.5	107	109.7	116	112.4	120.8	116.9	111.75

Source: Statistics Canada 2021h

The information about the tax on products and the margins for the gasoline commodity are given in Table 4.8. The margin share and tax rate of the second-generation ethanol commodity are assumed to be the same as those for gasoline produced by petroleum refineries (e.g., their proportion of trade margins to corresponding product supply at basic price are equal).

Table 4.8 Margin Value Vector of Gasoline and Price Estimates

Motor gasoline	Basic price	Trade margins	Transportation, gas and storage margins	Taxes on products	Purchaser price
Supply (M$)	33,711.0	12,151.2	974.1	15,921.5	62,757.8
price ($/L)	0.80	0.29	0.02	0.38	1.50
ratio	1	0.36	0.029	0.47	1.86

If $T_{ethanol}$ denotes the tax on the commodity, second-generation ethanol, then the purchaser price of second-generation ethanol ($P^{P}_{ethanol}$) can be estimated by multiplying the retail price of gasoline ($P^{R}_{gasoline}$) and the ratio of total supply at purchaser price ($q^{P}_{gasoline}$) to that at retail price ($q^{P}_{gasoline} - T_{gasoline}$).

$$P^{P}_{ethanol} = P^{P}_{gasoline} = P^{R}_{gasoline} \ \frac{q^{P}_{gasoline}}{q^{P}_{gasoline} - T_{gasoline}} = 1.50 \qquad (4.3)$$

Similarly, the basic price of second-generation ethanol ($P^{B}_{ethanol}$) is calculated by multiplying the purchaser price of gasoline ($P^{P}_{gasoline}$) by the proportion of total supply of gasoline at basic price ($q^{B}_{gasoline}$) to that at purchaser price ($q^{P}_{gasoline}$).

$$P^{B}_{ethanol} = P^{B}_{gasoline} = P^{P}_{gasoline} \ \frac{q^{B}_{gasoline}}{q^{P}_{gasoline}} = 0.80 \qquad (4.4)$$

4.4 Data Requirement for Scenario Development: Base Case Scenario

Before inserting data for the augmented SUTs, the SUTs had the imported ethanol removal, aggregation, and augmentation of tables were then done. In the analysis, second-generation ethanol is assumed to substitute for existing ethanol imports. As a result, modifying the Canadian SUTs incorporate two commodities (i.e., crop residues and second-generation ethanol) and a new industrial sector (i.e., second-generation ethanol industry). This subsection provides the detail data used in this process.

4.4.1 Ethanol Production Capacity in 2017

Canada imported motor gasoline and fuel ethanol in 2017. The total supply of motor gasoline was $33,710.96 million at basic price, while the value of imports was $7,068.9 million at basic price according to the Canadian SUTs in 2017. Approximately 20.97 percent of the motor gasoline demand was met by imports. The fuel ethanol imports were 1,402 million liters in 2017 (Bradford 2019). Although 2G ethanol might exist in the ethanol imports, its share might be very small considering its limited output and the advanced biofuel mandate in the US. Available data doesn't separate first-generation ethanol and second-generation ethanol in ethanol imports and thus all the ethanol imports are assumed to be first-generation ethanol in the analysis.

In the base-case scenario, the new domestic production of second-generation ethanol ($Vol_{ethanol}$) is supposed to be equivalent to the amount of current ethanol imports, 1,402 million liters. The supply of second-generation ethanol ($q_{ethanol}$) is the same as the value of ethanol imports ($I_{ethanol}$). The coefficient β is calculated to be the ratio of ethanol imports ($I_{ethanol}$) to the demand of domestic gasoline class ($q_{gasoline}$).

$$\beta = \frac{q_{ethanol}}{q_{gasoline}} = \frac{I_{ethanol}}{q^{B}_{gasoline} - I_{gasoline}} = \frac{Vol_{ethanol}\, P^{B}_{ethanol}}{q^{B}_{gasoline} - I_{gasoline}} \quad (4.5)$$

$$= \frac{1402 \times 0.8}{33710.96 - 7068.92} = 4.23\%$$

4.4.2 Cost Structure of Second-Generation Ethanol in 2017

Assuming all of the second-generation ethanol commodity sold are produced in the same year, the total supply of domestic second-generation ethanol ($q_{ethanol}$) in the second-generation ethanol industrial sector can be estimated according to the production of second-generation ethanol ($Vol_{ethanol}$) and the basic price of second-generation ethanol ($P^{B}_{ethanol}$):

$$q_{ethanol} = P^{B}_{ethanol}\, Vol_{ethanol} = 0.80 \times 1402 = 1127.68 \quad (4.6)$$

The next step is to prepare the data for the second-generation ethanol industrial sector in the supply and use tables. To introduce the second-generation ethanol industrial sector into the SUTs, one column representing this sector in both the use and supply table is added. In this industry, the specific number of ethanol plants (N) is determined by the total industrial production (1,402 million liters) and the capacity of the target plant (CAP_c) (176.50 million liter):

$$N = \frac{Vol_{ethanol}}{CAP_c} = \frac{1402}{176.50} = 7.94 \quad (4.7)$$

It is estimated that the sector has around 8 plants. Then, the revenue and cost structure in the Table 4.5 and Table 4.6 can be multiplied by N to get the revenue and cost structures for the whole industrial sector. The cost of building the second-generation plants should be \$1341.64 million.

4.4.2.1 Estimation the total revenue for the 2G ethanol industrial sector in 2017

In the supply table, the column of the second-generation ethanol industrial sector incorporates two non-zero elements representing the revenue of ethanol ($V^0_{ethanol,ethanol}$) and electricity ($V^0_{electricity,ethanol}$). The information is shown in Table 4.9.

Table 4.9 Estimation of Total Revenue for 2G Ethanol Sector in 2017

Ethanol production in 2017 (ML)	1,402.00
Ethanol basic price ($/L)	0.80
Total value of ethanol production in 2017 (M$)	1,127.68
Electricity production (million kW-h)	421.37
Electricity basic price ($/kW-h)	0.06
electricity value (M$)	23.49
Total revenue (M$)	1,151.17

4.4.2.2 Inputs for Ethanol Production

The cost structure of second-generation ethanol industrial sector at purchaser prices can be estimated by expanding the cost structure of target ethanol plant by N times. Therefore, 5.95 million MT of corn stover would be required to produce 1,402 million litres of ethanol. The total cost of corn stover is estimated to be $331.72 million. The value of other inputs is also expanded N times.

The tax on the output of the second-generation ethanol industrial sector in Canada is assumed to follow that of the petroleum refineries industrial sector. In other words, second-generation ethanol industrial sector and petroleum refineries industrial sector have the same ratio of tax on production to gross value-added at basic prices. Suppose $v_{tax,j}$ denotes the net tax on production in the sector j and VA_j represents the gross value-added at basic prices for sector j, the tax on production of second-generation ethanol industry can be estimated as follows.

$$v_{tax,ethanol} = v_{tax,gasoline} \frac{VA_{ethanol}}{VA_{gasoline}} = \$3.96\ million \qquad (4.8)$$

4.4.3 Preparation of the 2G Ethanol Industrial Sector and Commodities in the Canadian SUTs

The inputs of the second-generation ethanol industrial sector in the use and value-added matrix are based on the cost structure of second-generation ethanol industry. The purchaser price is converted to basic price using the margin value matrix shown in Table 4.10. In the use table, the new column of second-generation ethanol industry is inserted with several nonzero elements as shown in the basic price column of Table 4.11.

4.5 Data Requirement for Scenario Development: Scenario 1

In the first scenario, second-generation ethanol is assumed to replace 50 percent of the first-generation ethanol demand. Two commodities, crop residues and second-generation ethanol, as well as the second-generation ethanol industrial sector were incorporated into the SUTs.

4.5.1 Ethanol Production Capacity in 2017

The amount of ethanol consumed in 2017 was 3,047 million liters. Since the share of second-generation ethanol was trivial, it was assumed that all ethanol consumed was first-generation ethanol. The domestic production of first-generation bioethanol was estimated to be 1,645 million liters. Suppose domestic production of second-generation ethanol ($Vol_{ethanol}$) replaces half the domestic production of first-generation ethanol, this would be to 822.50 million liters. The coefficient δ can be calculated by dividing the total supply of second-generation ethanol (q_{ethanol}) to total demand of domestic gasoline ($q_{gasoline}$).

$$\delta = \frac{q_{\text{ethanol}}}{q_{gasoline}} = \frac{Vol_{ethanol}\, P^{B}_{ethanol}}{q^{B}_{gasoline} - I_{gasoline}} = \frac{822.50 \times 0.8}{33710.96 - 7068.92} = 2.48\% \qquad (4.9)$$

Table 4.10 Margin Value Matrix for Ethanol (M$)

Product class	wholesale margins – farm products	wholesale margins – machinery, equipment and supplies	wholesale margins – miscellaneous products	grain storage margins	air freight transportation services margins	rail freight transportation services margins	water freight transportation services margins	road transportation services for specialized freight margins	water transportation support, maintenance and repair services margins	road transportation support services margins	freight transportation arrangement and customs brokering services margins	other transportation support services margins	Taxes on products
crop residue	33.11	0.00	0.00	9.32	0.00	16.54	0.12	17.53	0.08	0.10	0.62	0.10	0.00
Electricity	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.73
Water delivered by water works and irrigation systems	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Sewage and dirty water disposal and cleaning services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Steam and heated or cooled air or water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67
Other basic inorganic chemicals and nuclear fuel	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
Basic organic chemicals, n.e.c.	0.00	0.00	14.31	0.00	0.00	0.63	0.02	10.58	0.01	0.04	0.24	0.07	0.39
Other industry-specific machinery	0.00	59.82	0.00	0.00	0.00	0.08	0.00	1.56	0.00	0.06	0.29	0.09	1.34
Total	33.11	59.82	14.33	9.32	0.00	17.25	0.14	29.71	0.08	0.20	1.15	0.26	4.19

Table 4.11 Cost Structure of the 2G Ethanol Industrial Sector (M$)

Product	Basic Price	Margin& Tax	Purchaser
Crop residue	254.21	77.51	331.72
Electricity	20.63	1.73	22.35
Water delivered by water works and irrigation systems	7.06	0.06	7.12
Sewage and dirty water disposal and cleaning services	72.92	0.00	72.92
Steam and heated or cooled air or water	41.80	0.67	42.47
Other basic inorganic chemicals and nuclear fuel	0.51	0.06	0.58
Basic organic chemicals, n.e.c.	188.05	26.29	214.34
Other industry-specific machinery	177.32	63.24	240.56
Wholesale margins - farm products	33.11	-	-
Wholesale margins - machinery, equipment and supplies	59.82	-	-
Wholesale margins - miscellaneous products	14.33	-	-
Air freight transportation services	0.00	-	-
Rail freight transportation services	17.25	-	-
Water freight transportation services	0.14	-	-
Road transportation services for specialized freight	29.71	-	-
Water transportation support, maintenance and repair services	0.08	-	-
Road transportation support services	0.20	-	-
Freight transportation arrangement and customs brokering services	1.15	-	-
Other transportation support services	0.26	-	-
Grain storage	9.32	-	-
Tax on product	4.19	-	-
Gross operating surplus	183.08	-	183.08
Taxes on production	3.96	-	3.96
Wages and salaries	32.07	-	32.07
Total	1,151.17	169.56	1,151.17

4.5.2 Cost Structure of the Second-Generation Ethanol Industrial Sector in 2017

For the second-generation ethanol industrial sector, the number of plants is determined by the total production ($Vol_{ethanol}$) and the capacity of the benchmark plant (CAP_c).

$$N = \frac{Vol_{ethanol}}{CAP_c} = \frac{822.50}{176.50} = 4.66 \quad (4.10)$$

Given this calculation, it was assumed that the industry required 5 plants. The revenue and cost structure in Table 4.5 and Table 4.6 were multiplied by N to get the revenue and cost structures for the whole industry. The cost of building the second-generation plants was estimated to be $787.09 million in this scenario. The total revenue, margin value matrix and cost structure for this sector was built up using the same method as that in the base case. The details are provided in Appendices C, D and E, respectively.

4.6 Data Requirement for Scenario 2

In scenario 2, it was assumed that E10 gasohol substitutes for 20% of the existing demand for domestic motor gasoline in 2017. The subsections reorganize the supply and use tables of the Statistics Canada's 2017 SUT and include two additional industrial sectors (second-generation ethanol and gasohol) and three new commodities (crop residues, second-generation ethanol, and gasohol) for the year 2017 at the national level. This procedure adds three rows representing the new commodities and two columns representing the new industrial sectors in both the supply and use tables.

4.6.1 Data Preparation of Gasohol

E10 gasohol is an additional new commodity compared to the base case. Gasohol is assumed to satisfy 20 percent of the initial demand of domestic motor gasoline and only be provided by the gasohol sector ($5109.79 million):

$$\mathrm{V}^{0}_{gasohol,gasohol} = 0.2\ \mathrm{V}^{a}_{gasoline,\ gasoline} = 5109.79 \quad (4.11)$$

where V_{ij} represents the supply of product i from industry j. The superscripts **0** represent the matrix after augmentation, while the superscripts $\boldsymbol{a}$ denote the initial matrix before augmentation. Gasohol is supposed to be consumed by all the sectors previously purchasing motor gasoline. Therefore, the purchases of gasohol can be derived by scaling down the initial demand of domestic motor gasoline. The data is provided in the 2017 Canadian use table.

$$U^{0}_{\mathrm{gasohol,j}} = 0.2\ \mathrm{U}^{\mathrm{a}}_{\mathrm{gasoline,j}}, \quad \forall\ \mathrm{j} \neq \mathrm{ethanol, gasohol} \tag{4.12}$$

$$f^{0}_{gasohol} = 0.2\ f^{\mathrm{a}}_{gasoline} \tag{4.13}$$

where $\mathrm{f_i}$ is the final demand of domestic product i and U_{ij} is the purchases of domestic product i by industry j.

The new gasohol industrial sector only provides the singular product, gasohol, without byproducts. The gasohol sector only consumes two intermediate inputs, motor gasoline and second-generation ethanol, but no primary inputs. The E10 gasohol is a low-concentration fuel mixture consisting of 10 percent second-generation ethanol and 90 percent gasoline. The gasoline and second-generation ethanol purchased by the gasohol sector are \$4598.82 million and \$ 510.98 million, respectively.

$$\mathrm{U}^{0}_{\mathrm{gasoline,gasohol}} = 0.9\ \mathrm{V}^{0}_{\mathrm{gasohol,gasohol}} = 4598.82 \tag{4.14}$$

$$\mathrm{U}^{0}_{ethanol,gasohol} = 0.1\ \mathrm{V}^{0}_{gasohol,gasohol} = 510.98 \tag{4.15}$$

4.6.2 Ethanol Production Capacity in 2017

Second-generation ethanol is one of the new commodities and corresponds to a new industrial sector. This subsection first considers the data for the commodity. The initial value of motor gasoline provided by petroleum refineries is \$25,548.97 million. E10 gasohol replaces 20% of the purchases and sales of motor gasoline class ($\pi = 20\%$ and $\alpha = 10\%$). As a result, 2% content in the gasoline pool is indeed second-generation ethanol in the Canadian economy. The value of second-generation ethanol purchased by the gasohol sector is \$510.98 million.

$$\mathrm{U}^{0}_{ethanol,gasohol} = 0.1\ \mathrm{V}^{0}_{gasohol,\ gasohol} = 510.98 \tag{4.16}$$

The total demand of second-generation ethanol can further be estimated by the intermediate input of ethanol going to gasohol industrial sector since the second-generation ethanol is all consumed by the gasohol industrial sector in the model. Moreover, the supply of second-generation ethanol is supposed to be equal to its demand which means the ethanol commodity produced in 2017 were all purchased in the same year. Based on the value of domestic second-generation ethanol consumed by the gasohol sector ($\mathrm{U}^0_{ethanol,gasohol}$), the total supply of domestic second-generation ethanol at basic price can be estimated with the assumption that total domestic 2G ethanol demand ($q_{ethanol}$) is equal to its supply:

$$q_{ethanol} = \mathrm{U}^0_{ethanol,\ gasohol} = 510.98. \tag{4.17}$$

Second-generation ethanol is further assumed to be only produced by its own industrial sector. Then the second-generation ethanol supply from its sector is \$510.98 million.

$$\mathrm{V}^0_{ethanol,ethanol} = q_{ethanol} = 510.98 \tag{4.18}$$

Assuming all the second-generation ethanol commodity sold are produced in the same year, the total production of the second-generation ethanol industry could be derived (635.28 million liter) according to the supply of domestic second-generation ethanol at basic price divided by the basic price of second-generation ethanol.

$$Vol_{ethanol} = \frac{q_{ethanol}}{P^B_{ethanol}} = \frac{510.98}{0.80} = 635.28 \tag{4.19}$$

4.6.3 Cost Structure of Second-Generation Ethanol Industrial Sector in 2017

The next step is to prepare the data for the second-generation ethanol industrial sector in the supply and use tables. To introduce the second-generation ethanol sector into the SUTs, one column representing this sector is added in both the use and supply tables.

The specific number of ethanol plants in the industrial sector is determined by the total production in the industry (635.28 million liters) and the capacity of the benchmark plant (CAP_c).

$$N = \frac{Vol_{ethanol}}{CAP_c} = \frac{635.28}{176.50} = 3.60 \quad (4.20)$$

Therefore, the sector has 4 plants. The revenue and cost structure in the Table 4.5 and Table 4.6 is multiplied by N to get the revenue and cost structures for this industry. The cost of building the second-generation plants is estimated to be $607.93 million. The total revenue, margin value matrix, and cost structure in this industry are derived using the same method as that in the base case. The details are provided in Appendices F, G, and H, respectively.

4.7 Data Preparation of GHG Estimation

In each scenario, several databases and models are utilized to estimate the GHG emissions because of second-generation ethanol production and use. First, data from the Greet software developed by Argonne National Laboratory is used to estimate the GHG emissions (Wang 2021). It is noteworthy that this estimation of GHG emission from feedstock and fuel production has incorporate the effect of land use and management from feedstock production. The Greet model was modified to estimate the GHG emission reductions that exclude the effect of land use change because the original Greet model is under the U.S. conditions. These data were used to for estimate the GHG emissions from feedstock and ethanol production in Canada (Table 4.12). The GHG emissions of gasoline is 0.607 Gg CO_2 eq per million liters, the emission of first- and second-generation ethanol are 0.809 and 0.157 Gg CO_2 eq per million liters.

GHGenius 5.01b, proposed by $(S\&T)^2$ Consultants Inc. (2021), is applied to estimate GHG emissions during combustion of transport fuel (Table 4.13). For net vehicle operation, GHG emissions of gasoline is estimated to be 2.46 Gg CO_2 eq per million liters, while the emissions from ethanol fuel is almost zero.

The IPCC provide more details of GHG emissions caused by land-use change (IPCC 2006; 2019; 2020). For first-generation ethanol, the effect of land use change from grassland to cropland was estimated. Since 90 percent of the forests are publicly owned and managed in Canada (Natural Resources Canada 2018), it was assumed that the new cropland is obtained from grassland. For every hectare, the change from grassland to cropland implies 62.25 tonnes of additional GHG emissions from land. The calculation is provided in Table 4.14. On the other hand, certain extra crop residues must be burned to avoid negative impact. If these residues are used to produce second-generation ethanol, it has the potential to reduce 12.9 tonnes of GHG emission for every hectare of land as shown in Table 4.15. The data is supported by the Database on GHG Emission Factor (IPCC 2020) and the method is derived from the IPCC report (2006; 2019).

Table 4.14 and 4.15 are further developed to build up the relationship between GHG emissions and ethanol output as shown in Table 4.16 and 4.17. In summary, 1 million liters of first-generation ethanol can produce 0.0168 CO_2 eq additional GHG emissions due to more croplands being converted from grassland, while 1 million liters of second-generation ethanol may result in a 0.0107 Mt CO_2 eq of GHG emission reduction due to less burning of crop residues. Considering that ethanol use also avoids potential GHG emissions caused by gasoline use, the estimates in the IPCC model can be extended to incorporate reduced GHG emissions from gasoline (0.00306 Mt/ML). The IPCC model gives new insight into the potential GHG emissions with these changes.

Table 4.12 GHG Emissions from Fuel and Feedstock Production

	Gasoline		**Corn Ethanol: Combined Dry and Wet Milling Ethanol**		**Corn Stover Ethanol: Fermentation**	
	Crude for Use in CA Refineries	CA Gasoline	Corn	Ethanol	Corn Stover	Ethanol
GHGs (g/mmBtu)	6,515.19	17,693.06	15,212.21	33,127.92	6,385.48	3,000.07
BTU/L	25,076.48		16,739.65		16,739.65	
GHGs (Mt/ML)	1.63E-04	4.44E-04	2.55E-04	5.55E-04	1.07E-04	5.02E-05
Total GHG (Mt/ML)	6.07E-04		8.09E-04		1.57E-04	

Source: Gable and Gable 2020, Wang 2021

Table 4.13 GHG Emissions during Net Vehicle Operation

Product	**GHG emission form net vehicle operation**	
	(g/litre)	(Mt/ML)
Ethanol	0	0
Gasoline (CGS360pps S)	2456	2.46E-03

Source: $(S\&T)^2$ Consultants Inc. 2021

Table 4.14 Change in Biomass Carbon from Grassland to Cropland

Area of Land Converted to Cropland	Biomass stocks before the conversion	Carbon fraction of dry matter	Biomass carbon growth	Loss of biomass carbon	Change in carbon stocks in biomass
(ha)	(tonnes dm ha^{-1})	[tonnes C (tonne dm)$^{-1}$]	(tonnes C yr^{-1})	(tonnes C yr^{-1})	(tonnes C yr^{-1})
$\Delta C_B = \Delta C_G - B_{BEFORE} \times \Delta A_{TO\_OTHER} \times CF - \Delta C_L$					
ΔA_{TO_OTHERS}	B_{BEFORE}	CF	ΔC_G	ΔC_L	ΔC_B
1	8.5	0.5	5	63	-62.25

Source: IPCC 2006, IPCC 2019, IPCC 2020

Table 4.15 GHG Emissions from Agricultural Residues Burning

Area burnt	Mass of fuel available for combustion[3]	Combustion factor	Emission factor for each GHG		GHG emissions from fire
(ha)	(tonnes ha^{-1})	(-)	[g GHG (kg dm burnt)$^{-1}$]		(tonnes)
$L_{fire} = A \times M_B \times C_f \times G_{ef} \times 10^{-3}$					
A	M_B	C_f	G_{ef}		L_{fire}
1	10	0.8	CH_4	2.7	0.022
			CO	92	0.74
			N_2O	0.07	0.00056
			NO_x	2.5	0.02
			CO_2	1515	12.12
			Total	1612.27	12.90

Source: IPCC 2006, IPCC 2019, IPCC 2020

Table 4.16 1G Feedstock Production: GHG Emissions from Land Use Change

Ethanol production	**Unit Converter: ethanol**	**Ethanol conversion factor: corn**	**Unit Converter: corn**	**Corn harvest**	**GHG Emission from land**	**Total GHG Emission**
(million liter)	(liter gallon^{-1})	(gallon bushel^{-1})	(MT bushel^{-1})	(MT ha^{-1})	(tonnes ha^{-1})	(Mt)
$\Delta L_{1G} = \Delta E_{corn} \div U_E \div C_{1G} \times U_C \div P_{1G} \times GL_{1G}$						
ΔE_{corn}	U_E	C_{1G}	U_C	P_{1G}	GL_{1G}	ΔL_{1G}
1	3.79	2.50	0.03	9.93	62.25	0.0168

Source: Danielson 2017, USDA 2003, US Grain Council 2021

Table 4.17 2G Feedstock Production: GHG Emissions from Land Management Change

Ethanol production	**Ethanol conversion factor: residue**	**Sustainable residues harvest**	**Unit Converter: land**	**GHG Emission from land**	**Total GHG Emission**
(million liter)	(liter tonne^{-1})	(tonne acre^{-1})	(acre ha^{-1})	(tonne ha^{-1})	(Mt)
$\Delta L_{2G} = \Delta E_{residue} \div C_{2G} \div P_{2G} \div U_L \times GL_{2G}$					
$\Delta E_{residue}$	C_{2G}	P_{2G}	U_L	GL_{1G}	ΔL_{2G}
1	235.62	5.12	2.47	-12.90	0.0107

Source: IPCC 2006, IPCC 2019, IPCC 2020

List of Notation

- CAP_c: capacity of the benchmark plant.
- $f^{a}_{gasoline}$: final demand of domestic motor gasoline before augmentation.
- $f^{0}_{gasohol}$: final demand of domestic gasohol after augmentation.
- $I_{ethanol}$: imports of ethanol products.
- $I_{gasoline}$: imports of motor gasoline class.
- N: the specific number of ethanol plants in 2G ethanol industry.
- $P^{B}_{ethanol}$: basic price of 2G ethanol.
- $P^{P}_{ethanol}$: purchaser price of 2G ethanol.
- $P^{P}_{residues}$: purchaser price of crop residues.
- $P^{R}_{ethanol}$: retail price of 2G ethanol.
- $q_{ethanol}$: demand of domestic 2G ethanol at basic price.
- $q_{gasoline}$: demand of domestic motor gasoline class at basic price.
- $q^{B}_{ethanol}$: total supply of 2G ethanol.
- $q^{B}_{gasoline}$: total supply of motor gasoline class at basic price.
- q^{B}_{grain}: total demand of grain (except wheat) at basic price.
- $q^{B}_{residues}$: total demand of crop residues at basic price.
- $q^{d}_{ethanol}$: total demand of domestic 2G ethanol at basic price.
- $q^{P}_{gasoline}$: total supply of motor gasoline class at purchaser price.
- q^{P}_{grain}: total demand of grain (except wheat) at purchaser price.
- $q^{P}_{residues}$: total demand of crop residues at purchaser price.
- $q^{s}_{ethanol}$: total supply of domestic 2G ethanol at basic price.
- $S_{residue}$: amount of domestic crop residues used in animal production sector.
- $T_{gasoline}$: total tax on gasoline.
- $U^{0}_{ethanol,gasohol}$: purchases of domestic 2G ethanol by gasohol industry at basic price after augmentation.

- $U^{0}_{\text{gasohol,j}}$: purchases of domestic motor gasoline at basic price by industry j after augmentation.
- $\mathrm{U}^{0}_{\text{gasoline,gasohol}}$: purchases of domestic motor gasoline class by gasohol industry at basic price after augmentation.
- $\mathrm{U}^{\mathrm{a}}_{\text{gasoline,j}}$: purchases of domestic motor gasoline by industry j at basic price before augmentation.
- $U^{B}_{residues,animal}$: cost of domestic crop residue purchased in animal production sector at basic price.
- $U^{P}_{residues,animal}$: cost of domestic crop residue in animal production sector at purchaser price.
- $\mathrm{V}^{0}_{electricity,ethanol}$: revenue of electricity products in 2G ethanol industry.
- $\mathrm{V}^{0}_{ethanol,ethanol}$: revenue of 2G ethanol products in 2G ethanol industry, or 2G ethanol supply from its sector at basic price.
- $\mathrm{V}^{0}_{gasohol,gasohol}$: gasohol products produced by gasohol industry after augmentation.
- $\mathrm{V}^{\mathrm{a}}_{gasoline,\ gasoline}$: supply of motor gasoline from petroleum refineries industry before augmentation.
- $v_{tax,ethanol}$: net tax on production in 2G ethanol industry.
- $v_{tax,gasoline}$: net tax on production in the gasoline industry.
- $VA_{ethanol}$: gross value-added at basic prices in 2G ethanol industry.
- $VA_{gasoline}$: gross value-added at basic prices in gasoline industry.
- $Vol_{ethanol}$: total production of 2G ethanol in second-generation ethanol industry.

Chapter 5: Results and Discussion

In the first three scenarios, the economic effect of expanding the second-generation industrial sector is estimated in two steps. First, the economic impact of the construction of the new ethanol refineries is summarized. Second, the macroeconomic effects of second-generation ethanol production are quantified, with estimates of industrial output, GDP, and employment. The interindustry effects are also described. The GHG emissions in each scenario are also estimated. In the last scenario, the volume of first- and second-generation ethanol that would need to be produced to obtain the GHG reduction target for the transportation sector in 2030 is estimated.

5.1 Base Case Scenario: Import Substitution Policy

In the base case, the study assumes the Canadian economy domestically produces the required ethanol to replace imports using second-generation ethanol technology. The intent is to reduce the dependence on fuel ethanol imports, especially from the US. Since 2011, Canada has imported fuel ethanol from the US due to the increased domestic demand driven by biofuel mandates (Bradford 2019). Canada imported 20.96 percent of the motor gasoline commodity in 2017 (Statistics Canada 2020). Of the total motor gasoline commodity, ethanol fuel imports (1.40 billion liters) accounted for 4.23 percent (Bradford 2019). This means that 45.97 percent of the total fuel ethanol used in gasoline relied on imports.

Besides import reduction, import substitution may result in economic stimulus and job creation. It also leads to foreign currency savings and thus lessening the pressure on foreign reserves (Li 2017). As a result, the import substitution policy in the base case is simulated first.

5.1.1 Construction of 2G Plant Impact

The construction of 8 second-generation ethanol plants increases the gross fixed capital formation in final demand by $1,341.65 million. The components of capital expenditure are shown in Table 4.4, which correspond to the change in final demand of each commodity. The economic impact of constructing the second-generation bioethanol plants is quantified using Equation (3.32). The direct effect is more significant on the engineering construction and manufacturing industrial sectors. The details are presented in Table 5.1. The main direct effect is on the other industry-specific machinery and other engine and power transmission equipment commodities, increasing their output by $679.00 million and $256.83 million, respectively. The demand for heating and cooling equipment (except household refrigerators and freezers) and the turbines, turbine generators, and turbine generator sets (except aircraft turbines) commodities increases by $122.68 million and $121.34 million for the construction of the second-generation ethanol plant.

Table 5.1 Base Case Scenario: Direct Effect of Construction of 2G Plants

Commodities	**Direct effect** (M$)	**Share (%)**
Industrial buildings (except mine buildings)	69.55	5.18%
Waterworks engineering works	6.25	0.47%
Sewage engineering works	9.38	0.70%
Material handling equipment	76.63	5.71%
Other industry-specific machinery	679.00	50.61%
Heating and cooling equipment (except household refrigerators and freezers)	122.68	9.14%
Other engine and power transmission equipment	256.83	19.14%
Turbines, turbine generators, and turbine generator sets (except aircraft turbines)	121.34	9.04%
Total	1341.65	-

The direct plus indirect effect of the plant construction is an increase in industrial output of $2,235.24 million (Table 5.2). The indirect effect is mainly on the machinery manufacturing industrial sector, raising its industrial output by $893.59 million (39.98% of the total increase). The construction benefits the industrial machinery manufacturing industry the most (20.08 percent of total increase), followed by the industrial sectors of engine, turbine and power transmission equipment manufacturing (14.04%), other general-purpose machinery manufacturing (10.36%), and ventilation, heating, air-conditioning and commercial refrigeration equipment manufacturing (5.65%). The impacts on other industrial sectors are relatively small. But it is notable that petroleum refineries and its upstream sector, oil and gas extraction industry, also benefit from the investment in second-generation ethanol, with an increase of $11.64 and $9.32 million, respectively.

Table 5.2 Base Case Scenario: Direct plus Indirect Effect of Construction of 2G Plants on Industry Output

Industries	**Output change** (M$)	**Share (%)**
Industrial machinery manufacturing	448.81	20.08%
Engine, turbine and power transmission equipment manufacturing	313.92	14.04%
Other general-purpose machinery manufacturing	231.48	10.36%
Ventilation, heating, air-conditioning and commercial refrigeration equipment manufacturing	126.40	5.65%
Non-residential building construction	69.55	3.11%
Commercial and service industry machinery manufacturing	67.24	3.01%
Iron and steel mills and ferro-alloy manufacturing	56.14	2.51%
Machinery, equipment and supplies merchant wholesalers	37.18	1.66%
Machine shops, turned product, and screw, nut and bolt manufacturing	34.75	1.55%
All the other industrial sectors	849.77	38.03%
Total	2,235.24	-

As illustrated in Table 5.3, the direct effect of the construction of the ethanol plants is estimated to increase industrial output by $1,341.65 million, which leads to an increase in employment and GDP. It is estimated that 5,377 workers are employed to construct the plant and the GDP increases by $559.83 million. The employment and GDP coefficients that were applied were from the industrial machinery manufacturing and oil and gas engineering construction sectors. Due to the direct and indirect effect of the construction, the economy experiences an increase in industrial output of $2,235.24 million, GDP of $1,127.54 million and employment of 8,652.62 jobs.

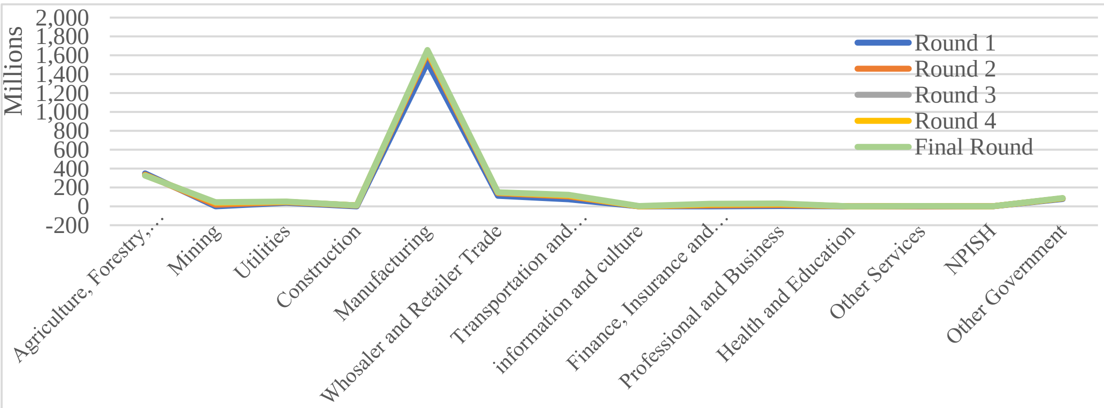
Table 5.3 Base Case Scenario: The Direct Effect and Direct Plus Indirect Effect of Building 2G Ethanol Plants on the Economy in terms of Industrial Output, GDP, and Employment.

	Industrial Output ($ million)	GDP ($ million)	Employment Jobs
Direct Effect	1341.65	669.83	5,377.80
Direct plus Indirect Effect	2,235.24	1,127.54	8,652.62

5.1.2 RAS-Rebalancing the Model with 2G Ethanol

In this subsection, the impact of expanding second-generation ethanol production is estimated. The RAS method is applied to provide both the stepwise change and final situation of the Canadian economy. The increase in total sectoral output is estimated to be $2.51 billion, which is 0.067 percent of the initial total industrial output. The second-generation ethanol industry contributes $1.15 billion, which is 0.031 percent of the total industrial output. The economy also experiences an increase in employment of 4,792 new jobs (an increase of 0.026 percent) where the second-generation ethanol industry provides an additional 142 jobs. The GDP increases by 0.035 percent, or an increase is $663.00 million. The second-generation ethanol industrial sector contributes $215.16 million to GDP, accounting for 32.45 percent of overall GDP growth.

Figure 5.1 Base Case Scenario: Change in Sectoral Output



The increase in sectoral output ($1.66 billion) is considerable in the manufacturing sector since the second-generation ethanol industry is part of this sector. Agricultural, forestry, fishing and hunting sectors also experience a relatively rapid rise ($324.48 million) in their industrial output. Wholesale and retail trade sectors follow, with a modest increase of $148.01 million. The impacts on the other sectors are relatively small.

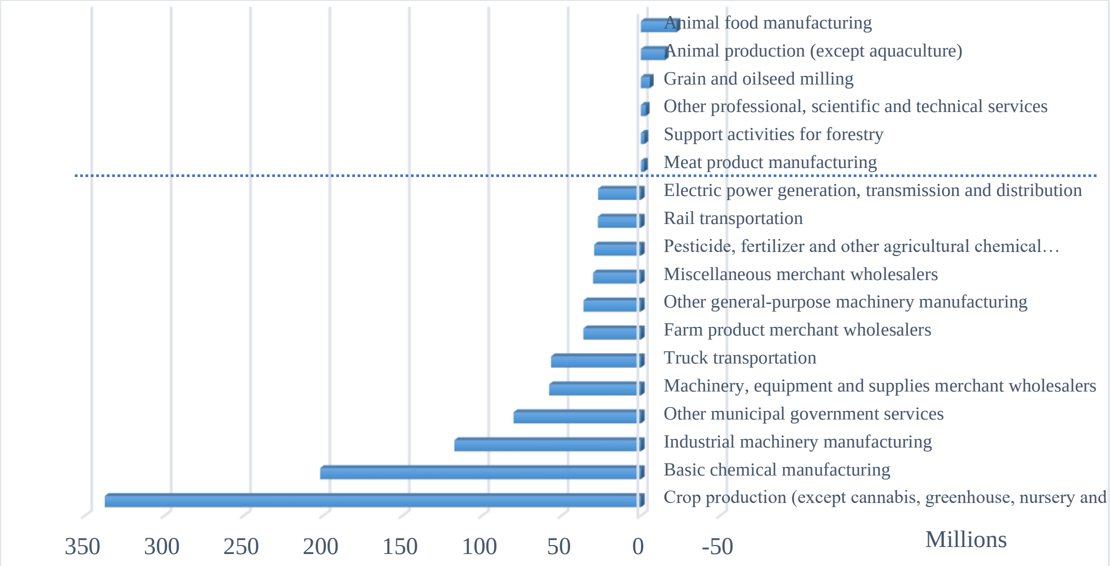
Figure 5.2 shows aggregate changes in the top industries (at the detailed level). The upstream sectors of the second-generation ethanol industry benefit more from ethanol production in comparison with other industries. The output in water, sewage and other systems sector has the highest increase (2.94 percent). Industrial machinery manufacturing (2.59 percent), basic chemical manufacturing (1.17 percent), farm product merchant wholesalers (0.92 percent), and crop production[3] (0.86 percent) industries show relatively rapid growth in industrial output. Apart from the second-generation ethanol industry, crop production industry contributes the most to the change in total industrial output, increasing by $337.62 million. Following that are basic chemical manufacturing ($201.94 million), industrial machinery manufacturing ($117.38 million) and other municipal government services industries ($80.16 million). The expansion of the second-generation ethanol industrial sector increases the output of the petroleum refineries industry by 0.043 percent.

The increase in industrial output from the crop production sector leads to a higher demand for their inputs, such as pesticides and other agricultural chemicals. The reason for this is that approximately 72.60 percent of these domestic products flow to the crop production industry. The corresponding industrial output is estimated to increase by $29.43 million (0.50 percent). However, the economic stimulus in agricultural and manufacturing sectors is partly offset by the decrease in the animal production sector ($13.79 million) and animal food manufacturing ($22.50 million) over time. Competing

[3] In this study, the category of crop production refers to crop production (except cannabis, greenhouse, nursery and floriculture production), since greenhouse, nursery and floriculture production as well as cannabis production are separate industry classes in the SUTs at the detailed level.

for crop residues with the second-generation ethanol industry, the animal production industry[4] and its downstream sector, animal food manufacturing industry, have the largest decrease in output among industries.

Figure 5.2 Base Case Scenario: Aggregate Change in Industrial Output



Industries of animal food manufacturing and support activities for forestry show a rather faster decline in industrial output, falling by 0.26 and 0.10 percent, respectively. Animal production, grain and oilseed milling, and other professional, scientific and technical services industries also experience a modest decrease (0.02-0.05 percent). The industries of grain and oilseed milling, and other professional, scientific and technical services industries decrease their output by $5.66 million and $3.12 million, respectively, while industries of support activities for forestry, meat product manufacturing suffer a slight loss in output (around $2 million). These decreases are relatively small given the increase in total industrial output.

The changes in sectoral employment are estimated assuming a fixed rate of employment per dollar of output for every industry. The employment in the utility sector

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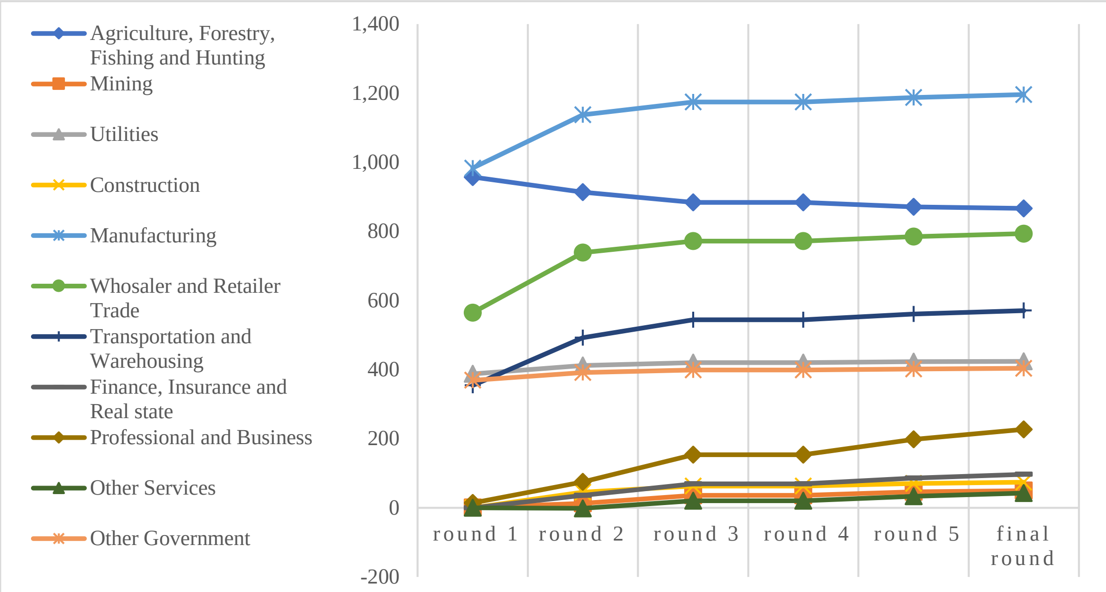
[4] In this study, the industry class of animal production refers to animal production (except aquaculture) where aquaculture industry is listed separately.

increases more rapidly, by 0.35 percent, as well as that in the agriculture, forestry, fishing and hunting sector (0.22 percent). The new jobs in the manufacturing sector (1,196) and the agricultural, forestry, fishing and hunting sector (867) together account for 43.05 percent of the total job creation.

Figure 5.3 Base Case Scenario: Change in Sectoral Employment



The water sewage and other systems industry has the highest growth in employment (2.94 percent) followed by the industrial machinery manufacturing industry (2.59 percent). Together these two sectors employ an additional 843 persons. When compared to other industries, the industrial sectors with relatively large increases in output are the basic chemical manufacturing (1.17 percent), farm product merchant wholesalers (0.92 percent), and crop production (0.86 percent). The crop production industry provides 928 new jobs, 19.36 percent of the total new jobs. Modest decreases in employment are seen in the animal production industry (73 jobs), while small reductions in employment are seen in the animal food manufacturing (30 jobs), support activities for forestry industries (23 jobs), and other professional, scientific and technical services industry (16 jobs).

The GHG emissions were estimated after the expansion of the second-generation ethanol production, as recorded in Table 5.4. The gasoline pool incorporates motor gasoline, first-generation ethanol, and second-generation ethanol. The GHG emissions of the gasoline pool was extended to include GHG emissions, from only net vehicle combustion (calculated by GHGenius model) of fuel and feedstock production (estimated by the Greet Model) as well as land-use change (quantified by the IPCC model). The GHG emissions from gasoline production and combustion are 18.96 and 76.73 Mt CO2eq, respectively. The emissions of first- and second-generation ethanol are quantified by the Greet, GHGenius 5.01b, and IPCC models. According to GHGenius 5.01b database, the emissions from ethanol combustion are negligible. The use of ethanol has the potential to reduce the use of the same amount of gasoline. When the change in GHG emissions are estimated using the IPCC model, the reduced emissions caused by less gasoline use are also taken into consideration. To be specific, first-generation ethanol produces 1.67 Mt CO2eq of GHG emissions during fuel and feedstock production. The GHG emissions from first-generation ethanol estimated by the IPCC model was 29.68 Mt CO2eq. The GHG emissions from second-generation ethanol production based on crop residues are 0.22 Mt CO2eq, while the estimate for second-generation ethanol in the IPCC model is -18.54 Mt CO2eq, which is equivalent to a reduction of 4.03 million passenger vehicles for one year (EPA 2021).

Table 5.4 Base Case Scenario: GHG Emissions from the Gasoline Pool (Mt)

Model	Gasoline	1G ethanol	2G ethanol	Change
Greet	18.96	1.67	0.22	0.22
GHGenius	76.73	0	0	0.01
IPCC	-	29.68	-18.54	-15.09

Total emissions from the gasoline pool increases by 0.23 Mt CO2 eq without GHG reductions from the residue combustion. The increase is mainly caused by additional GHG emissions (0.22 Mt CO2eq) during second-generation ethanol production as well as feedstock cultivation and collection compared to that of first-generation ethanol imports. The increase in motor gasoline (2.23 million liters) contributes an extra 0.01

Mt CO2eq. Although ethanol import substitution brings significant economic stimulus, it increases net GHG emissions at the same time. However, if the feedstock of the second-generation ethanol had been planned to be burnt, GHG savings could be 15.09 Mt CO2eq. This reduction has the same effect as having 3.3 million passenger vehicles less for a year.

Table 5.5 shows the changes in emissions before and after the import substitution policy. The description of this policy scenario is given on Page 39 in Section 3.2.3. After the RAS rebalancing, second-generation ethanol is estimated to be 1,410 million liters, accounting for 4.06 percent of the gasoline pool. To demonstrate the change in GHG emissions using different fuels and the contribution of second-generation ethanol, GHG emissions from the same amount of motor gasoline, first- and second-generation ethanol were estimated. When 4.06 percent in the gasoline pool is provided by motor gasoline, the GHG emissions are estimated to be 4.32 Mt CO2eq. The figures are 1.14 and 0.22 Mt CO2eq for first- and second-generation ethanol, respectively. For that reason, the use of first-generation ethanol results in a reduction of 3.18 Mt CO2eq in GHG emission, whereas the consumption of second-generation ethanol decreases the GHG emissions by 4.10 Mt CO2eq.

Table 5.5 Base Case Scenario: GHG Emissions Comparison (Mt)

Model	Gasoline	1G ethanol	2G ethanol
Greet	0.84	1.14	0.22
GHGenius	3.48	0	0
Total	4.32	1.14	0.22
Reduction	-	3.18	4.10

5.1.3 Impact Analysis of Second-Generation Ethanol Production

After the RAS rebalancing, the impact analysis can be applied to estimate the macroeconomic effect of further expansion of the second-generation ethanol industrial sector. The direct effect is the original change in final demand. In the base case scenario, the direct effect of an increase in second generation ethanol is $798.59 million of second-generation industrial output (1,402 million liters). With this increase in output, employment increases by 98.23 jobs while GDP increases by $149.25 million. Moreover, the direct and indirect effect of the increased final demand of second-generation ethanol increases the industrial output by $1,895.96 million. The impact is felt in the GDP with an increase of $717.37 million, while the total employment increases by 4,068 jobs, as indicated in Table 5.6.

Table 5.6 Base Case Scenario: The Direct Effect and Direct Plus Indirect Effect of an Increase in 2G Ethanol on the Economy in terms of Industrial Output, GDP, and Employment.

	Industrial Output ($ million)	GDP ($ million)	Employment Jobs
Direct Effect	798.59	149.25	98.23
Direct plus Indirect Effect	1,895.96	717.37	4,068.01

5.2 Scenario 1: First-Generation Substitution Policy

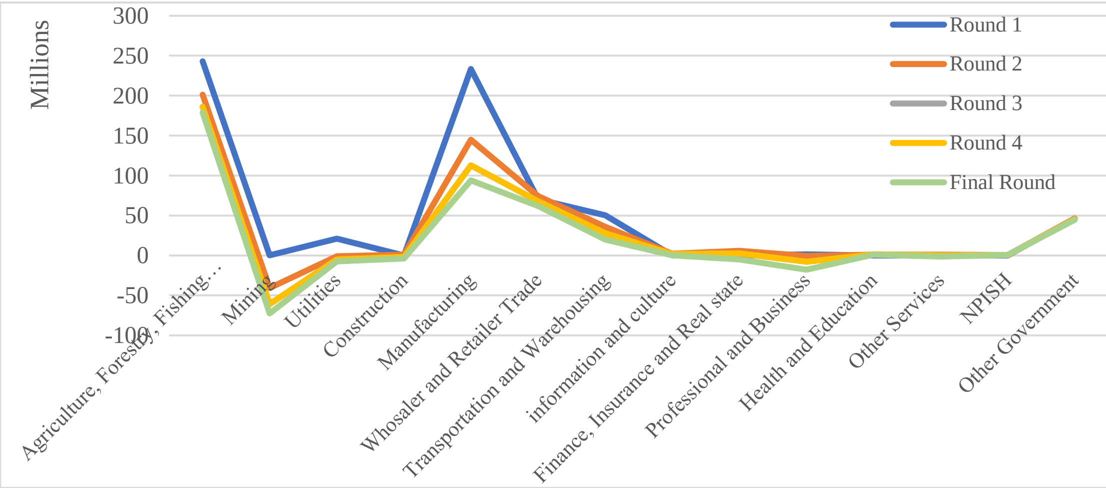
In Scenario 1, It is assumed that the Canadian economy domestically produces half the required domestic ethanol using agricultural residues as a feedstock rather than conventional feedstock. The construction of this scenario is driven by the environmental benefits of second-generation ethanol in comparison with that of first-generation ethanol.

In 2017, the amount of fuel ethanol used was 3.05 billion liters. This induced 1,645 million liters of domestic production and 1402 million liters of imports. First-generation ethanol dominated the Canadian ethanol market with only trivial consumption of second-generation ethanol (less than 0.5 percent of total ethanol use). It is assumed that half the domestic ethanol consumed is replaced by second-generation ethanol. This means that 822.50 million liters of first-generation ethanol are substituted by second-generation ethanol, which represents 2.48 percent in the total domestic motor gasoline class. This amount of second-generation ethanol required is within the capacity of second-generation ethanol production (774.77 -1691.77 million liters) from corn residues in Canada.

5.2.1 RAS-Rebalance of the Model with 2G Ethanol

This section discusses the consequences of increased second-generation ethanol production. Total sectoral output, taking into account industrial sector increases and decreases, is projected to increase by $293.78 million, or 0.0078 percent. The second-generation ethanol industrial sector adds $675.37 million of industrial output, a share of 0.018 percent in total output. The total employment rises by 1,074 new jobs (0.0057 percent), with second-generation ethanol sectors generating an additional 83 jobs. The GDP grows by 0.0020 percent, that is $38.53 million, while the second-generation ethanol industrial sector adds $126.22 million to GDP.

Figure 5.4 Policy Scenario 1: Change in Sectoral Output



New second-generation ethanol production replaces existing domestic first-generation ethanol, this results in the most significant benefits in the agricultural sector during the adjustment process. The increase in sectoral output is considerable in agricultural, forestry, fishing and hunting sectors ($178.89 million). However, this increase is slightly mitigated by the reduced output in the animal production industrial sector over time. In addition, the manufacturing sector experience a modest rise ($94.03

million) in output, mainly contributed by the second-generation ethanol industrial sector, which is tempered by decreasing output in the basic chemical manufacturing industrial sector as well as the animal production industrial sector. The wholesale and retail trade sector follows, with an increase of $62.12 million, as does other government ($44.54 million), as well as the transportation and warehousing sector ($20.06 million). On the other hand, the mining sector has a moderate decrease in output ($72.50 million). The substitution policy also leads to a slight reduction in the sectoral output of professional and business industrial sector ($17.73 million) as well as the utilities industrial sector ($7.28 million).

The most significant shift in industries (at the detailed level) is shown in Figure 5.5. The industries providing inputs for the second-generation ethanol industrial sector gain more from ethanol production in comparison with other industries. Water, sewage and other systems industrial sector and industrial machinery manufacturing industrial sector have the highest growth rate (around 1.5 percent) in output. Farm product merchant wholesalers (0.56 percent) and crop production (0.49 percent) industrial sectors experience a relatively rapid increase in output. The crop production industrial sector contributes $192.90 million to the increase in total output. The industries of industrial machinery manufacturing and other municipal government services also see a notable increase, $68.40 million and $41.81 million, respectively.

The basic chemical manufacturing industrial sector, which incorporates first-generation ethanol refineries, decreases its output by $645.51 million, which is slightly lower than the increase in the second-generation ethanol sector ($675.37 million). Cellulosic ethanol production negatively affects several upstream sectors of the basic chemical manufacturing industrial sector, with an output decrease in industries of oil and gas extraction[5] ($53.46 million), non-ferrous metal (except aluminum) production and processing ($17.83 million), petroleum refineries ($21.52 million), electric power

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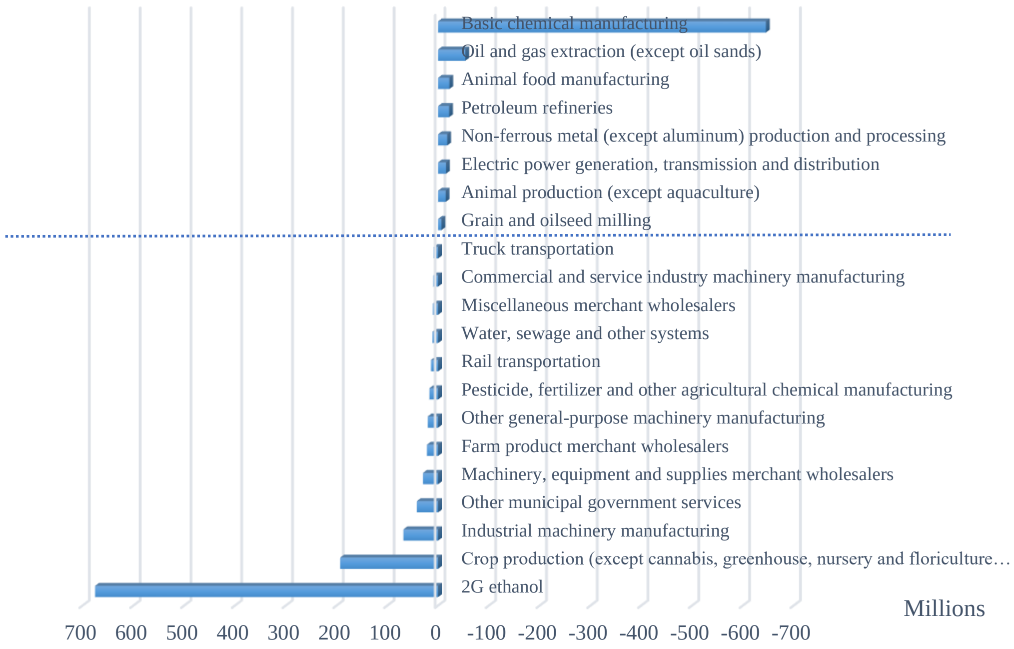
[5] In this study, the industry class of oil and gas extraction refers to oil and gas extraction (except oil sand). The oil sand extraction is classified as a separate industry in the Canadian SUTs at the detailed level.

generation, transmission and distribution ($15.42 million). The fall in industrial output of the petroleum refineries industrial sector alleviates the pressure on gasoline imports.

Figure 5.5 Policy Scenario 1: Aggregate Change in Sectoral Output

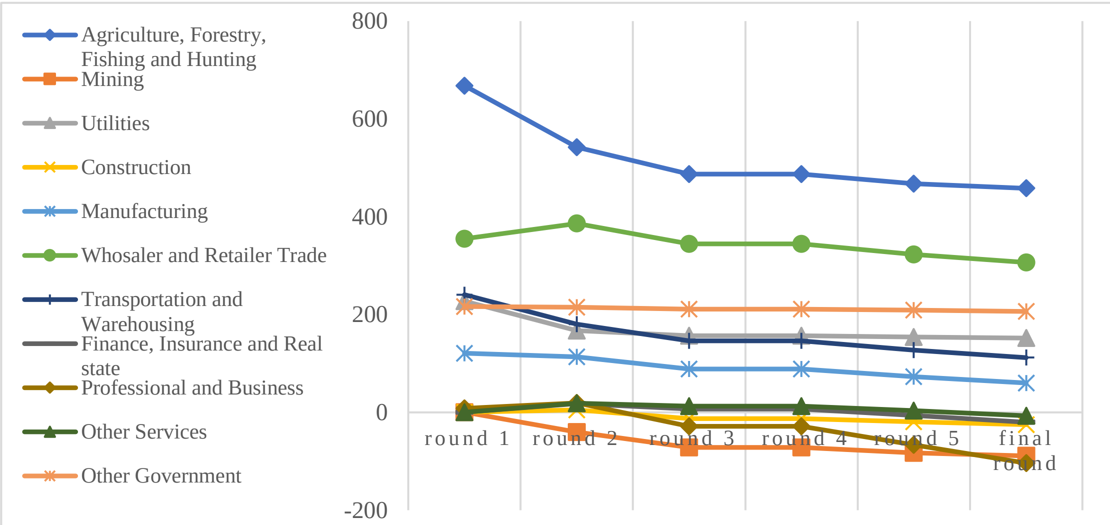


The animal food manufacturing and animal production industrial sectors show a relatively rapid decline in industrial output, decreasing by 0.26 and 0.053 percent, respectively. The output in other non-metallic mineral mining and quarrying (except diamond and potash) industrial sectors decreases by 0.19 percent, while oil and gas extraction, petroleum and coal product manufacturing (except petroleum refineries), crude oil and other pipeline transportation, non-ferrous metal (except aluminum) production and processing industrial sectors as well as grain and oilseed milling industrial sector experiences a decrease between 0.047-0.097 percent. These industries with lower growth rates in industrial output provide inputs for either the basic chemical manufacturing industrial sector or the animal production industrial sector.

The employment in the agriculture, forestry, fishing and hunting sector experiences a faster increase of approximately 0.12 percent, as well as that in the utility sector (0.13 percent). The new employment in the wholesale and retail trade sector (307) and agricultural, forestry, fishing and hunting sector (458) contribute 71.20 percent to the total increase in employment. Due to the larger share in total industrial output, the crop production industrial sector provides more additional jobs (530), as well as the industrial machinery manufacturing industrial sector (277).

On the other hand, the professional and business industrial sector experiences the largest decrease in employment (104). The employment in the mining sector decreases gradually over time, 89 people lose jobs in this sector. The industries of oil and gas extraction (46) and support activities for oil and gas extraction (20) employ fewer people. A significant reduction in employment is seen in the basic chemical manufacturing sector (445). The industries of animal production (78) and animal food manufacturing (29) also suffer job losses, as well as electric power generation, transmission and distribution (31).

Figure 5.6 Policy Scenario 1: Change in Sectoral Employment



In this scenario, gasoline consumption in Canada produces 18.49 Mt CO_2 eq of GHG emission during production and 74.82 Mt CO_2 eq due to burning fuels. For first-generation ethanol, the emissions driven by fuel and feedstock production are estimated to be 1.01 Mt CO_2 eq. It is noteworthy that the GHG emissions quantified by the IPCC model for the first-generation ethanol is 18.46 Mt CO_2eq. The significant increase in GHG emissions is mainly caused by the possible land use change from grassland to cropland, though the emissions from alternative gasoline consumption has been deducted from the estimate. On the other hand, second-generation ethanol demand slightly raises GHG emission by 0.13 Mt CO_2 eq. The amount is an order of magnitude less compared to that of first-generation ethanol. Moreover, it also has the potential to reduce GHG emission by 10.88 Mt CO_2 eq according to the IPCC model. The decrease is caused by possible fewer residues burnt in the field and avoided gasoline consumption. This reduction in GHG emissions is equivalent to 2.37 million fewer passenger vehicles per year. The overall changes in GHG emissions from gasoline pool are estimated in Table 5.7, which is caused by substituting domestic second-generation ethanol for 50 percent of existing domestic first-generation ethanol.

Table 5.7 Policy Scenario 1: GHG Emissions from the Gasoline Pool (Mt)

Model	Gasoline	1G ethanol	2G ethanol	Change
Greet	18.49	1.01	0.13	-0.54
GHGenius	74.82	0	0	-0.01
IPCC	-	18.46	-10.88	-22.69

The GHG emissions reduction is estimated to be 0.544 Mt CO_2eq without land use change. The GHG reduction for net vehicle operation is relatively small (0.007 Mt CO_2eq), while a larger reduction (0.537 Mt CO_2eq) happens when second-generation ethanol production replaces the first-generation production. On the other hand, when considering land use change and related management, a significant decrease in GHG emission (22.69 Mt CO_2eq) occurs because of more cropland reverted to grassland as well as fewer residues being burnt in the field. Therefore, the first-generation substitution policy leads to a net GHG emissions reduction and has the potential to decrease GHG emissions when biofuel feedstock production is based on more sustainable land use and management. In terms of GHG emissions reduction, it performs better as compared to an import substitution policy.

Table 5.8 shows the changes in GHG emissions before and after the first-generation substitution policy. The development of this policy scenario is provided on Page 40 in

Section 3.2.3. In this scenario, second-generation ethanol is estimated to be 827 million liters, contributing 2.48 percent to the gasoline pool. The GHG emissions from the same amount of second-generation ethanol are 0.13 Mt CO2eq, while the emissions from the same volume of gasoline and first-generation ethanol are 2.53 and 0.67 Mt CO2eq, respectively. Therefore, second-generation ethanol has the potential to reduce 0.54 Mt CO2eq more GHG emissions as compared to first-generation ethanol.

Table 5.8 Policy Scenario 1: GHG Emission Comparison (Mt)

Model	**Gasoline**	**1G ethanol**	**2G ethanol**
Greet	0.50	0.67	0.13
GHGenius	2.03	0	0
Total	2.53	0.67	0.13
Reduction	-	1.87	2.40

5.2.2 Impact Analysis of Second-Generation Ethanol Production

In Scenario 1, the first-generation substitution policy involves an increase ($468.50 million) in final demand of 2G ethanol commodity and a decrease ($468.50 million) in the final demand of the 1G ethanol commodity. As a result, there is no aggregated direct effect in terms of industrial output and employment since the employment coefficient for the first-generation ethanol industrial sector is assumed to be the same as that of the petroleum refineries industrial sector and the second-generation ethanol industry. Considering the direct and indirect effects as shown in Table 5.9, the industrial output and GDP increase by $183.97 million and $55.58 million, respectively. The employment experiences an increase of 1,270 jobs.

Table 5.9 Scenario 1: The Direct Effect and Direct Plus Indirect Effect of 1G Substitution Policy on the Economy in terms of Industrial Output, GDP, and Employment.

	Industrial Output ($ million)	GDP ($ million)	Employment Jobs
Direct Effect	0	-17.70	0
Direct plus Indirect Effect	183.97	55.58	1,269.51

5.3 Scenario 2: Second-Generation Biofuel Mandate

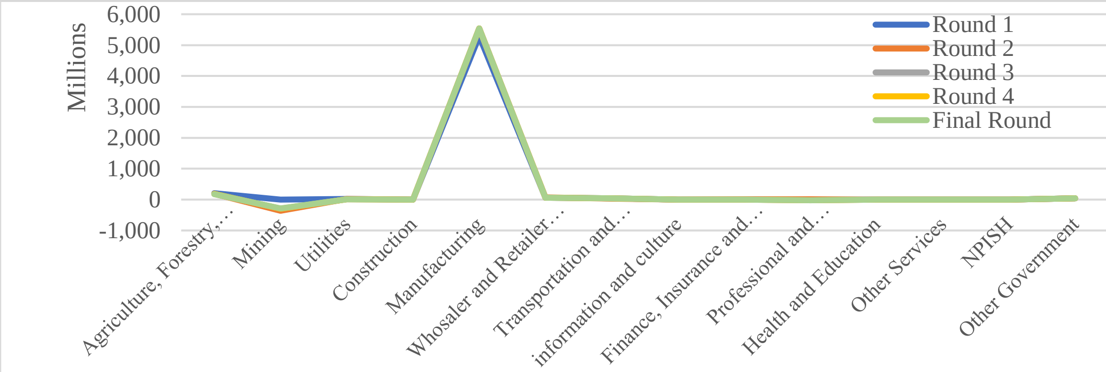
In this scenario, the new second-generation ethanol and gasohol industrial sectors are introduced to simulate an advanced biofuel mandate. This policy would have E10 gasohol substitute for 20 percent of the domestic motor gasoline demand in Canada, leading to $5,109.79 million of gasohol demand. As a result, the gasohol sector increases the demand for gasoline and second-generation ethanol by $4,598.82 and $510.98 million. In fact, 2 percent of the initial motor gasoline is designed to be replaced by second-generation ethanol. Therefore, before RAS rebalancing, the total value of gasoline, gasohol, and second-generation ethanol are $25,037.97, $510.98, $5,109.79 million, respectively.

5.3.1 RAS-Rebalance of the Model with 2G Ethanol

This section focuses on the impact of expanding second-generation ethanol production. The increase in total industrial output is estimated to be $5.57 billion, 0.15 percent of the initial total industrial output. The second-generation ethanol and gasohol industrial sectors together contribute $5.87 billion to the total industrial output, a share of 0.16 percent in total output. The total employment increases by 2,483 people in which gasohol and second-generation ethanol sectors added 1,030 jobs. The GDP growth rate is 0.0039 percent, implying a $74.04 million increase. Nonetheless, the new second-generation sector contributes $101.58 million to the GDP.

The change in industrial output varies by sector. The manufacturing sector increases its output by 0.78 percent over time, with additional production of $5.54 billion. The mining sector sees a slight increase ($0.22 million) in the output at the early stages, however, the increase is offset and finally becomes a decrease ($285.75 million). The professional and business sector, construction sector, and finance, insurance and real estate sector follow a similar path. The moderate increase in output is seen in the agricultural, forestry, fishing and hunting sector (0.19%), contributing around $179.62 million more to total sectoral output. The changes in other sectors are trivial. The change in industrial output in each round is depicted in Figure 5.7.

Figure 5.7 Policy Scenario 2: Change in Industrial Output by Sector

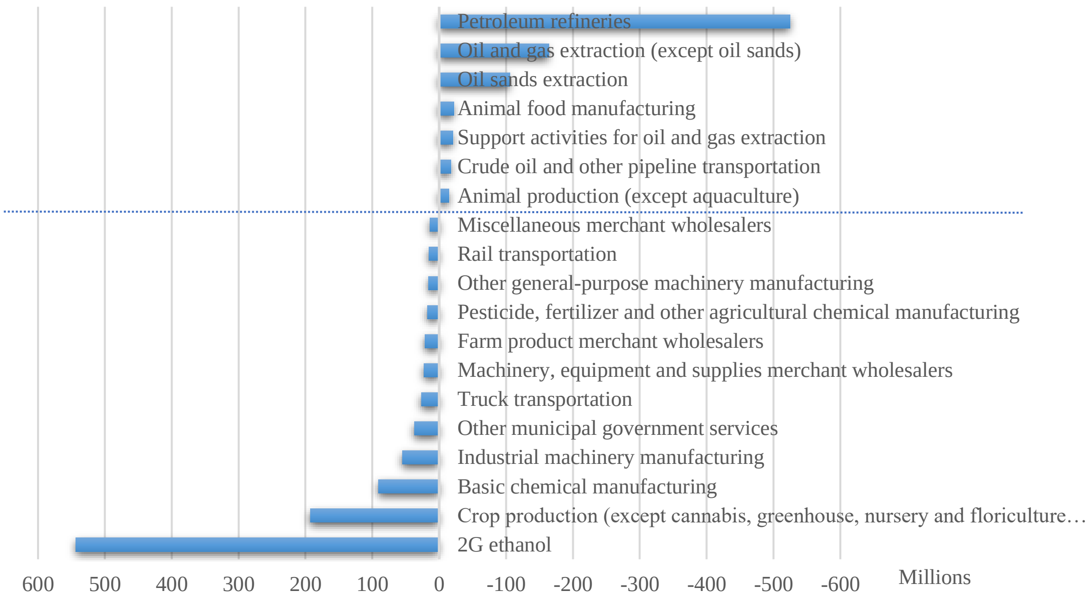


The industrial sector (at the detail level) that are most effected, either positively or negatively, are given in Figure 5.8. The industrial sectors that sell commodities to the second-generation ethanol industrial sector benefit the most from ethanol production. Sectoral outputs increase faster in water, sewage and other systems industrial sector and industrial machinery manufacturing industrial sector by around 1.2-1.4 percent. Industries of farm product merchant wholesalers, basic chemical manufacturing, crop production, and pesticide, fertilizer and other agricultural chemical manufacturing also modestly benefit from the new ethanol refineries, increasing their output by 0.30 to 0.55 percent. The output in the crop production industrial sector is projected to grow by $192.98 million. The basic chemical manufacturing industrial sector shows an increase of $91.06 million in its industrial output. The industrial machinery manufacturing industrial sector and other general-purpose machinery manufacturing industrial sector contribute an additional $71.07 million to total industrial output to support the expanding ethanol, crop, and petroleum production.

Other municipal government services industrial sector provides 93.24 percent of the domestic water delivered by water works and irrigation systems and 95.08 percent of the sewage and dirty water disposal and cleaning services. These products account for 9.56 percent of the total production costs for second-generation ethanol production.

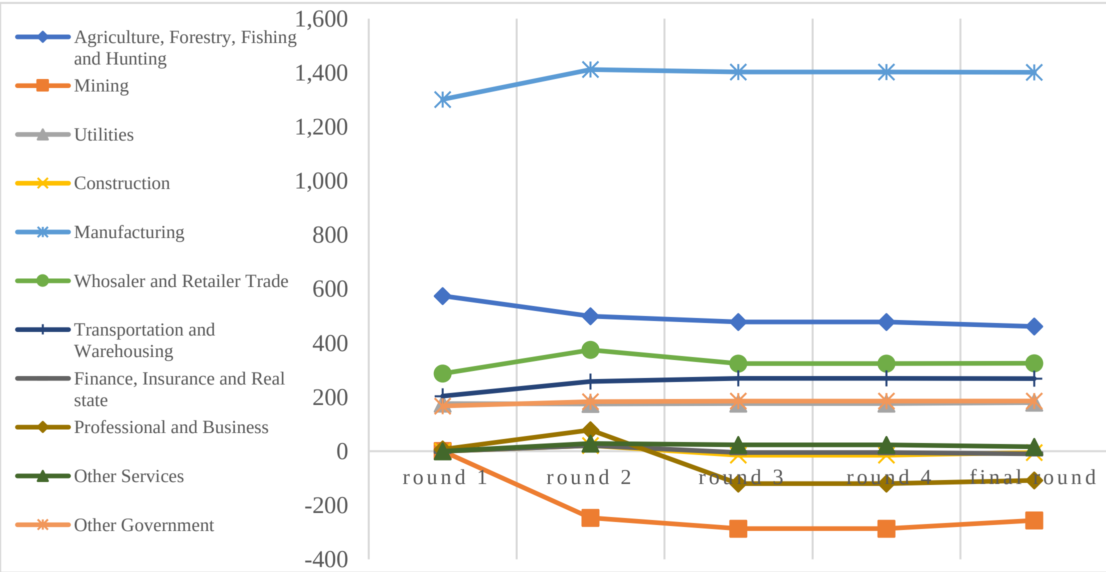
The industrial output change ($37.38 million) in this sector may be driven by higher input demand by the second-generation ethanol industrial sector. In addition, the truck transportation industrial sector dominates the road transportation service for general freight and specialized freight market with market shares of 97.41% and 98.25% respectively. This transportation service is purchased by various industrial sectors including the industries most effected in this scenario. The increase in industrial output (26.31 M$) of the truck transportation industrial sector is the result of a larger proportion of truck transportation industrial sector in the total output considering the medium growth rate in its industrial output.

Figure 5.8 Policy Scenario 2: Aggregate Change in Industrial Output



The advanced mandate has a negative effect on the industrial output of the petroleum refineries industrial sector ($525.02 million loss) as well as its upstream industries such as oil and gas extraction ($164.17 million), and oil sand extraction ($105.67 million). In the initial setting, 2 percent of the gasoline content is assumed to be replaced by second-generation ethanol. The further expansion of the ethanol industry stimulates petroleum production, which alleviates a considerable decrease in output of the petroleum refineries industrial sector during the first several rounds. Finally, the petroleum refineries industrial sector decreases its output by 0.85 percent. As expected, the oil and gas extraction industrial sector combined with the oil sand extraction industrial sector follow a similar path as the gasoline sector due to the forward linkages. They exclusively provide conventional crude oil and synthetic crude oil (48.59% of total cost in petroleum refineries) for gasoline production. Meanwhile, animal production (except aquaculture) and its downstream sectors such as the animal food manufacturing industrial sector also slightly suffer from this mandate with a decrease of $14.51 and $21.92 million in output respectively. The reduction slows down the growth in total output.

Figure 5.9 Policy Scenario 2: Change in Sectoral Employment



The employment in each sector is further estimated based on sectoral output. The advanced mandate raises employment in the utility sector by 0.15 percent, implying 180 new employees. Following that, the relatively rapid growth in employment of agricultural, forestry, fishing and hunting sector leads to 461 new jobs, or an increase of 0.12 percent. The largest increase in employment is seen in the manufacturing sector (1,401 jobs), contributing 56.45 percent of the total increase in employment. This increase is a function of its larger share in total industrial output, considering its growth rate of 0.088 percent. In addition, the wholesale and retail trade sector employs 325

Table 5.10 Policy Scenario 2: Employment Change in Most Effected Industrial Sectors

Industry (M$)	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6	Round 7	Round 8	Final Round
Gasohol	655.45	655.50	655.47	655.47	655.47	655.47	655.47	655.47	655.47
Crop production	573.91	544.47	538.36	538.36	532.67	532.67	532.67	530.95	530.95
2G ethanol	359.49	374.56	374.59	374.59	374.57	374.57	374.57	374.57	374.57
Industrial machinery manufacturing	212.22	215.02	223.42	223.42	223.67	223.67	223.67	223.70	223.70
Other municipal government services	164.60	171.64	177.40	177.40	177.67	177.67	177.67	177.71	177.71
Water, sewage and other systems	162.12	162.41	170.81	170.81	170.99	170.99	170.99	171.02	171.02
Machinery, equipment and supplies merchant wholesalers	120.70	138.46	117.34	117.34	120.72	120.72	120.72	121.68	121.68
Truck transportation	85.76	111.52	114.21	114.21	114.76	114.76	114.76	115.22	115.22
Farm product merchant wholesalers	95.39	98.51	98.03	98.03	97.34	97.34	97.34	97.18	97.18
Warehousing and storage	76.01	93.82	95.08	95.08	94.74	94.74	94.74	94.68	94.68
Miscellaneous merchant wholesalers	47.30	70.00	70.55	70.55	70.23	70.23	70.23	70.02	70.02
Basic chemical manufacturing	46.16	57.35	61.84	61.84	62.62	62.62	62.62	62.74	62.74
Architectural, engineering and related services	0.00	2.68	-44.57	-44.57	-36.12	-36.12	-36.12	-35.14	-34.97
Oil sands extraction	0.00	-60.16	-44.22	-44.22	-44.15	-44.15	-44.15	-44.13	-44.11
Petroleum refineries	-88.62	-64.60	-64.64	-64.64	-64.60	-64.60	-64.60	-64.58	-64.58
Animal production	0.60	-61.08	-69.72	-69.72	-74.34	-74.34	-74.34	-76.09	-76.85
Support activities for oil and gas extraction	0.02	0.17	-103.99	-103.99	-77.90	-77.90	-77.90	-77.10	-76.94
Oil and gas extraction	0.00	-190.57	-143.65	-143.65	-141.83	-141.83	-141.83	-141.53	-141.47

more people, while the transportation and warehousing sector offers 269 new jobs. On the other hand, the mining sector and professional and business sector provide 256 and 109 fewer jobs after the adjustment in which employment finally reduces by 0.011 and 0.0048 percent compared to the initial number.

The change in employment of labor-intensive industries is more significant in comparison with that in its industrial output. Besides the second-generation ethanol and gasohol sectors, the largest job increase (530) is provided by the crop production industrial sector as it has a higher labor-intensive (2.75/M$) compared to the basic chemical manufacturing sector (0.69/M$). Some other labour-intensive industries, particularly water, sewage and other systems industrial sector (16.82/M$), provide an additional 171 jobs. The path of the employment change of the most effected industries is shown in Table 5.10.

After the expansion of the second-generation ethanol industrial sector, GHG emissions from gasoline are 18.56 and 75.09 Mt CO_2eq at the stage of production and net vehicle operation, respectively, as indicated in Table 5.11. The GHG emissions from first-generation ethanol production are 1.67 Mt CO_2eq, whereas the potential emissions are estimated to be 30.69 Mt CO_2eq by the IPCC model. Nevertheless, second-generation ethanol emits far less greenhouse gas (0.11 Mt CO_2eq) compared to first-generation ethanol by the Greet model. Also, it may lead to considerable GHG reductions (8.44 Mt CO_2eq) according to the IPCC model. The reduction happens because second-generation ethanol production consumes excessive crop residues which are sometimes burnt and avoids gasoline consumption. It is equivalent to the emissions of 1.84 million passenger vehicles driven for one year (EPA 2021).

Table 5.11 Policy Scenario 2: GHG Emission from Gasoline Pool (Mt)

Model	**Gasoline**	**1G ethanol**	**2G ethanol**	**Change**
Greet	18.56	1.67	0.11	-0.30
GHGenius	75.09	0	0	-1.63
IPCC	-	30.69	-8.44	-7.13

The application of second-generation ethanol technology leads to a 0.3 Mt CO_2eq of aggregated GHG emissions reductions during the feedstock and fuel production process. The GHG emissions reductions for net vehicle operation is 1.63 Mt CO_2eq, while considerable reduction (7.13 Mt CO_2eq) happens if second-generation ethanol production consumes excessive crop residues that might be burnt. The GHG emissions reductions are larger compared to that of the first-generation substitution policy without potential land use changes. For this reason, if existing land use and management are sustainable without crop residue combustion in the field and new grassland cultivated, the advanced mandate will contribute more to the GHG emissions reductions target.

In this scenario, second-generation ethanol is estimated to be 666 million liters, contributing 2 percent to the gasoline pool. Table 5.12 shows the comparison of GHG emissions from 2 percent of gasoline, first- and second-generation ethanol in the gasoline pool. The emissions from this amount of first- and second-generation ethanol are 0.54 and 0.11 Mt CO_2eq, respectively. However, the emissions from the same volume of gasoline are much higher, 2.04 Mt CO_2eq, and thus a siginificant reduction in GHG emissions is made when second-generation ethanol is used (1.94 Mt CO_2eq). Comparing first- and second-generation ethanol production, second-generation ethanol has 0.43 Mt CO_2eq, lower GHG emissions than first-generation ethanol.

Table 5.12 Policy Scenario 2: GHG Emission Comparison (Mt)

Model	**Gasoline**	**1G ethanol**	**2G ethanol**
Greet	0.40	0.54	0.11
GHGenius	1.64	0	0
Total	2.04	0.54	0.11
Reduction	-	1.50	1.94

The GHG emissions from second-generation ethanol in the first three scenarios are compared in Table 5.13. After the RAS procedure, the volumes of second-generation ethanol are 1410, 827, and 666 million liters in these scenarios, respectively. When the blending rate of second-generation ethanol increases, its GHG emissions reductions are larger. The difference in GHG emissions is caused by the amount of second-generation ethanol used in the different scenarios.

Table 5.13 Comparison: GHG Emission of 2G Ethanol (Mt)

Model	Base Scenario	Scenario 1	Scenario 2
Greet	0.22	0.13	0.11
GHGenius	0	0	0
IPCC	-18.54	-10.88	-8.44

Table 5.14 specifies changes in emissions before and after the advanced mandate. The description of the policy scenarios are given on Page 41 in Section 3.2.3. For the gasoline pool supported by domestic products of motor gasoline, first- and second-generation ethanol, aggregated GHG emissions from fuel and feedstock production are 20.86, 19.60, and 20.34 Mt CO_2eq in the first three scenarios, respectively. The GHG emissions from fuel combustion are 76.73, 74.69, and 75.09 Mt CO_2eq. In addition, the IPCC model estimates GHG emissions at 11.14, 7.58, and 22.25 Mt CO_2eq in these scenarios. During the production and combustion process, it is noteworthy that aggregated GHG emissions slightly increase by 0.23 Mt CO_2eq from the base scenario of import substitution policy because of new second-generation production as well as additional motor gasoline demand. Nonetheless, first-generation substitution policy and advanced mandate will lead to GHG emissions reductions where the advanced mandate has higher GHG emissions savings compared to first-generation substitution policy with a lower blending rate.

Table 5.14 Comparison: GHG Emission from Gasoline Pool (Mt)

Model	Base Scenario		Scenario 1		Scenario 2	
	Total	Change	Total	Change	Total	Change
Greet	20.86	0.22	19.60	-0.54	20.34	-0.30
GHGenius	76.73	0.01	74.69	-0.01	75.09	-1.63
IPCC	11.14	-15.09	7.58	-22.69	22.25	-7.13

On the other hand, if current land use is not sustainable, involving reclamation of grassland and crop residue burning, the substitution policy will benefit the environment more as compared to the advanced fuel mandate, especially the first-generation substitution policy. As a result, the environmental effect of these policies varies considering current land use and management.

5.3.2 Impact Analysis of Second-Generation Ethanol Production

In Scenario 2, the advanced mandate involves changes in two elements in the initial final demand vector. The final demand for gasohol experiences an increase of $3,773.42 million, while the final demand for motor gasoline is reduced by the same amount. The direct effect on industrial output and employment is zero, while the GDP decreases by $14.26 million because of the lower share of value added in the second-generation ethanol industrial sector compared to the petroleum refineries industrial sector. The direct plus indirect effect is estimated to be an increase of $3,921.65 million in industrial output, with employment and GDP increasing by 1,011 jobs and $44.07 million, respectively. The direct effect and total effect are summarized in Table 5.15.

Table 5.15 Scenario 2: The Direct Effect and Direct Plus Indirect Effect of 2G mandate on the Economy in terms of Industrial Output, GDP, and Employment.

	Industrial Output ($ million)	GDP ($ million)	Employment Jobs
Direct Effect	0	-14.26	0
Direct plus Indirect Effect	3,921.65	44.07	1,010.97

5.4 Scenario 3: Achieving GHG Target in 2030

Scenario 3 investigates the amount of first-generation or second-generation ethanol that would be required to achieve the GHG reduction target for the transportation sector. Canada's existing Nationally Determined Contributions (NDC) for the Paris Agreement promises to reduce greenhouse gas emissions by 30% below 2005 levels by 2030. In 2017, the greenhouse gas emissions were 714 Mt CO_2eq (ECCC 2020a). The transportation sector accounts for 25.57% of Canada's greenhouse gas emissions or

182.57 Mt (Natural Resources Canada 2020d).

The government of Canada has committed to reduce its GHG emissions to 503 Mt by 2030 which is greater than the 30% reduction below 2005 levels. In this plan, the transportation sector is expected to emit 151 Mt GHG in 2030 (ECCC 2020c). In the 2020 reference case, the GHG emission by the transportation sector in 2030 was estimated to be 178 Mt CO_2eq (ECCC 2020b). Therefore, the target for the transport sector is to reduce their GHG emissions by 27 Mt CO_2eq in 2030.

As indicated in Table 5.16, when one liter of gasoline is replaced by first-generation ethanol, it decreases GHG emissions by 2.25 kg CO_2eq, while the number for second-generation ethanol is 2.91 kg CO_2eq. These estimates are based on the GHG emissions during fuel combustion and production which exclude the emission caused by land use change. To achieve the transportation emission goal in 2030, 11.98 billion liters of gasoline should be replaced by first-generation ethanol. It implies 35.95 percent of first-generation ethanol in the gasoline pool. On the other hand, 9.29 billion liters of second-generation ethanol would be needed to attain the target. Thus, the blending rate of second-generation ethanol is estimated to be 27.90 percent.

Table 5.16 Fuel Ethanol Used to Achieve GHG Target in 2030

Biofuel	**reduction in GHG**[6]	**volume**	**blending rate**
	(kg liter^{-1})	(million liter)	
1G ethanol	2.25	11,979.44	35.95%
2G ethanol	2.91	9,291.29	27.90%

5.5 Discussion

Three policy scenarios were constructed in the analysis: import substitution policy, first-generation substitution policy, and an advanced mandate. Second-generation bioethanol production leads to economic gains overall although it slightly reduces the output in

[6] This class refers to the amount of GHG reduction (gram) when one liter of gasoline is replaced by ethanol.

animal production industrial sector and its downstream industries because of feedstock competition. Second-generation ethanol production also contributes to the energy security by decreasing the dependency on ethanol imports. The import substitution policy leads to a larger domestic economic stimulus without replacement of gasoline and first-generation ethanol. On the other hand, the first-generation substitution policy and the advanced mandate further makes Canada more independent of gasoline imports, considering Canada is a net gasoline importer of $863.85 million in 2017. This substitution policy will contribute significantly to GHG emission reductions.

In the analysis, second-generation ethanol production is driven by biofuel policies. Government initiatives have played a significant role in biofuel development (Arndt et al. 2012; Osmani and Zhang 2013; Scaife et al. 2015; Su et al. 2015). These policies are significant in achieving the environmental goals. Policymakers should focus on second-generation biofuels and revise policy regimes to take advantage of diverse advanced biofuels (Banse et al. 2008b; De Lucia and Bartlett 2014). Fiscal incentives and consumption mandates for second-generation biofuel, for example, should be differentiated from those for first-generation biofuels (Carriquiry et al. 2011; Doumax-Tagliavini and Sarasa 2018).

Governments have used a variety of measures to develop advanced biofuels worldwide, enabling them to compete with gasoline and first-generation biofuel. Some research highlights the importance of policy mixes rather than a single biofuel policy. Different policy mixes have various effects on the economy. To begin, public investment in research and development helps ensure that the technologies are commercially feasible. Enhancing competitiveness via R&D activities is critical in filling the gap between demand driven policies and the presence of appropriate technologies for the production of second-generation biofuels. This would assist in determining a sustainable path for advanced biofuel industry and a move towards a low-carbon economy (De Lucia and Bartlett 2014; Scaife et al. 2015).

Subsidies can be designed to encourage biofuel production through decreased production costs or stimulate biofuel consumption through blending subsidies. A case study in the Midwestern United States revealed that variable subsidy policies reduced risks more effectively than fixed subsidy policies (Osmani and Zhang, 2017). Campbell (2018) estimated that in Canada the required subsidy to increase first-generation ethanol production would be \$0.63/liter, while that for cellulosic ethanol from hybrid poplar might be much higher with direct production subsidy of \$0.27/liter and implicit or blending subsidy of \$0.87/liter. Cellulosic ethanol needs higher subsidies to offset the cost of attracting additional land for hybrid poplar cultivation. Biofuel production from agricultural and forest residues may avoid land use issues and related costs. In addition, rural development may benefit more from direct subsidies compared to a higher excise tax on fossil fuels (Doumax-Tagliavini and Sarasa, 2018). However, research suggests that the U.S. subsidies might only slightly stimulate biofuel investment (Babcock 2012). Market-driven investment incentives (e.g., higher gasoline price) may significantly outperform biofuel subsidies in terms of investment and expansion of the US ethanol industry (Babcock 2012).

Biofuel mandates motivate energy producers and purchasers to embrace biofuel by blending mandates which support GHG reduction goals. The results of this research suggest that the second-generation biofuel mandate should be considered in the biofuel policy mix. In addition, other policies may supplement biofuel mandates and alleviate the negative impact of feedstock competition. For example, supplementing bioenergy-promoting policies by increased forest conservation helped lower the price of forest industry by-products in Sweden (Bryngemark 2020). A study also found that biofuel targets for GHG emission reduction performed better in comparison to increased excise taxes on transport fuels since the transportation market is skewed by high levies (Boeters et al. 2008). De Lucia and Bartlett (2014) concluded that if high tariffs were imposed on international imports, domestic production would satisfy the biofuel demand and increase farmer income and employment in the EU. The results from this study are consistent with their study. However, early research suggested that import restrictions directly undermined the performance and cost-effectiveness of Canada's increased consumption mandate (Le Roy et al. 2011). Therefore, policymakers should be cautious about the mix of biofuel policies including mandates and imports restrictions.

Finally, biofuels may be more appealing when conventional fuels are taxed, particularly via carbon credit schemes. Carbon taxes have the potential to increase advanced biofuel consumption, although previous studies indicated that a substantial increase would be possible only if these taxes were partly spent on biofuel subsidies in Canada (Campbell et al. 2018). In addition, Doumax-Tagliavini and Sarasa (2018) evaluated a biofuel policy mix that included a higher excise tax rate on fossil fuels and removal of direct subsidies for first-generation biofuels to promote advanced biofuels in the EU. This mix might meet the road transport fuel mandate, but had a detrimental effect on the biofuel industry's profitability (Doumax-Tagliavini and Sarasa 2018; Kretschmer et al., 2009). On the other hand, Babcock (2012) found that the blender tax credit might not benefit the biofuel sector if the biofuel mandate was still useful in increasing the demand for the biofuels. When biofuel demand (e.g., driven by high gasoline prices) exceeded mandated levels, the biofuel sector might profit from the combination of blender tax credit and mandate. However, the livestock sector would suffer significantly since global corn prices were much higher. The higher corn prices also increased energy prices and the costs of mandates.

These findings suggest that appropriate complementary measures may be required to guarantee the profitability of the cellulosic ethanol industry. Also, the stability and continuity of biofuel policies are significant. In the world's leading states, governments reduce biofuel investment risk by providing sustained and cost-sharing privileges that decrease subsidies for the whole process of the biofuel industry (Su et al. 2015). Frequent policy shifts depress the activities in the biofuel industry. Market volatility in conventional fuel, the volatility of the Renewable Fuel Standard program, and blender tax credits have various impacts on biofuel investment and production as well as policy effectiveness (Markel et al. 2018). The lack of coordination and integration of the federal-provincial policy framework for second-generation biofuel industry might be one of the principal regulatory barriers in Canada (Lubieniechi and Smyth 2016). For example, regional discrepancies in technical biofuel mandates and blending standards throughout Canada may act as an impediment to interprovincial trade (Scaife et al. 2015).

Lessons learned from first-generation biofuel policies may be useful. For example, complete environmental consequences of 2nd-generation biofuel production from certain feedstocks should be studied. Some researchers further suggest that cellulosic biofuel policy must be implemented cautiously to avoid impairing biodiversity and counteract climate policy (Scaife et al., 2015; Smith et al., 2013; Melillo et al. 2009; Boeters et al. 2008).

Chapter 6: Conclusion

6.1 Problem Situation and Objectives

The amount of renewable fuel in gasoline and diesel pools in Canada has increased over the past 10 years. However, current domestic biofuel output is insufficient to fulfill current biofuel mandates, and this has resulted in an expansion of the domestic supply-demand imbalance and increasing reliance on ethanol imports. Canada has the potential to produce more domestic biofuels than the mandated level. Second-generation biofuels are being developed in Canada using a wide range of feedstocks and technologies.

Currently, Canadian ethanol is mainly from feedstock such as grain which may negatively influence food supply and not substantially achieve GHG emission reductions. Other limitations, such as energy consumption and utilization of arable lands, as well as the fuel vs food debate should also be taken into consideration. Many countries, including Canada, highlight second-generation biofuels as a fossil fuel substitute. Nonetheless, it is unclear how advanced biofuel production and policies will affect the Canadian economy.

Previous research has shed light on crop residues as a biofuel feedstock in Canada. This kind of feedstock may both alleviate pressure on land and have relatively high GHG emission reductions. Agricultural residues are largely not used in Canada. For example, wheat straw and corn stover are among the largest agricultural residues in Canada. This thesis regards corn resides as the main feedstock for second-generation biofuel production.

A gap in the literature is that few studies have incorporated the bioethanol industry from agricultural residues into the Canadian economy. This research contributes to accomplishing this goal. The main objective of the thesis is to investigate the economic-wide impact of second-generation bioethanol production in Canada with several biofuel policies. The policy scenarios are estimated to provide policy implications. The policy scenarios include an import substitution policy, 1G substitution policy, and an advanced mandate. In each of these scenarios, the macroeconomic impact of incorporating the new industry on GDP, employment, and total industrial output are estimated. The study sheds light on the economic connectedness between the second-generation biofuel industrial sector and other industrial sectors in the economy. Furthermore, the GHG emissions derived from the gasoline pool are quantified. In the last scenario, the blending rate of first- and second-generation ethanol in the gasoline pool that is required to achieve the GHG emission goal in 2030 is estimated.

6.2 Method

The method used to conduct the study is input-output (IO) analysis. The IO model is a common macroeconomic model that analyzes the interconnection of different industries and final demand sectors. The IO analysis was chosen for this study because it provides more details when investigating the economic connectedness between specific industries and other industries. The Canadian SUTs at the detail level have several agricultural industries and other petroleum refining sectors. The thesis uses this detail to emphasize the effect on these industries using this framework. The rectangular SUTs incorporate byproducts and provides a more accurate estimate than symmetric IO or CGE models. Therefore, the rectangular SUTs are utilized to integrate the second-generation ethanol industrial sector from crop residues into the economy.

In the analysis, the macroeconomic effects are quantified using the Canadian supply and use tables (SUTs) for 2017 from Statistics Canada. In the SUTs, competitive imports are removed from the intermediate inputs and final demands to take into consideration this leakage. Then, certain empty rows and columns with trivial data are deleted as well as commodities that are completely imported. Taking the above into accounting, the supply and use tables included 478 commodities and 233 industries. The direct and indirect effect of constructing the second-generation ethanol plants on the economy was estimated based on this framework. However, the second-generation ethanol sector is not included in the existing SUTs framework. As a result, the SUTs were augmented to integrate the new industrial sector and commodities into the basic analysis and extended scenarios. To rebalance the SUTs with the new industrial sector and commodities, the adjustment procedure proposed by Malik et al. (2014) was employed. The modified "biproportional" matrix balancing (RAS) technique is advantageous since both the industry technology matrix and market shares matrix remain the same during the rebalancing process. In addition, the impact of further second-generation ethanol expansion is analyzed following the "biproportional" matrix (RAS) rebalancing.

6.3 Results and Scenarios

The study first simulates an import substitution policy and further constructs two policy scenarios, a first-generation substitution policy and an advanced biofuel mandate. In the basic analysis and these two scenarios, the construction of the second-generation production facilities are simulated to estimate the direct and total effects of this change. Also, the macroeconomic impact of ethanol production from corn residues is evaluated as well as the sectoral effect.

Overall, the second-generation ethanol investment in the construction of the ethanol plants and ethanol production leads to economic stimulus and increased employment and GDP. The total direct effect of building the second-generation ethanol facilities leads to economic stimulus for the industries providing inputs for the facility construction and industrial machinery manufacturing. These include the industrial sectors of engineering construction and industrial machinery manufacturing. In the base case scenario, the direct effect of building the second-generation ethanol facilities (with a capacity of 1,402 million liters ethanol) leads to a significant increase in industrial output ($1,341.65 million), GDP of $669.83 million, and 5,377 new jobs. The direct plus indirect effect increases the industrial output, GDP, and employment by $2,235.24 million, $1,127.54 million, and 8,652 jobs, respectively. Second-generation ethanol production stimulates upstream industrial sectors significantly. However, the main impacts vary by scenario and therefore the economic effect of second-generation ethanol production is different for certain sectors, particularly mining and manufacturing sectors.

In the basic analysis, the ethanol imports are replaced with second-generation ethanol which accounts for 4.23 percent of the initial total demand for domestic motor gasoline class. The second-generation ethanol production results in an increase of $2.51 billion in direct plus indirect output, which is 0.067 percent of the initial total industrial output. The second-generation ethanol industrial sector contributes $1.15 billion to the total industrial output, a share of 0.031 percent of total output. The Canadian economy also sees an increase in employment of 4,792 new jobs. The GDP increases by 0.035 percent, that is $663.00 million. The second-generation ethanol industrial sector contributes $215.16 million to GDP, accounting for 32.45 percent of the total increase in GDP. In addition, the increase in second-generation ethanol benefits the manufacturing sectors significantly, followed by agricultural, forestry, fishing and hunting sector, as well as the wholesale and retail trade sectors. The expansion of the second-generation ethanol industrial sector increases the output in the petroleum refineries industrial sector. After the RAS rebalancing, the further increase ($798.59 million) in final demand with second-generation ethanol will lead to a direct plus indirect effect of an additional $1,895.96 million in industrial output, $717.37 million more in GDP, and 4,068 new jobs. As expected, the economy benefits by substituting domestic ethanol for imported ethanol.

In Scenario 1, 50 percent of the existing domestic first-generation ethanol is substituted by new second-generation ethanol, which represents 2.48 percent of the initial total demand of the domestic gasoline class. Using the RAS method, the new second-generation ethanol production increases total industrial output by $293.78 million, or 0.0078 percent. The second-generation ethanol industrial sector contributes $675.37 million to the total industrial output, a share of 0.018 percent of total output. The economy also experiences a growth in employment by 1,074 new jobs (an increase of 0.0057 percent) and in GDP with an additional $38.53 million (a rise of 0.0020 percent). The contribution of the second-generation ethanol industrial sector is estimated to be $126.22 million to GDP. The largest economic stimulus occurs in the agricultural, forestry, fishing and hunting sector with this policy. The manufacturing sector also has a moderate increase in sectoral output. This is followed by the wholesale and retail trade sectors, other government sector and transportation and warehousing industrial sectors. This substitution policy also results in a moderate reduction in output of the mining sector and professional and business sector, respectively. This is mainly driven by decreases in output in the basic chemical manufacturing industrial sector and its forward linkages. Cellulosic ethanol production not only reduces the demand for first-generation ethanol, but also slightly decreases the rebalanced output in the petroleum refineries sector and its upstream sectors. The effect may lessen the demand for imported gasoline. After the SUTs rebalancing, the impact analysis is further applied to show that replacing $468.50 million of first-generation ethanol in final demand with second-generation ethanol leads to an economic stimulus. For the total effect, the industrial output increases by $183.97 million, while GDP sees an increase of $55.58 million, and 1,270 new jobs.

In Scenario 2, an advanced bioethanol mandate is estimated where 20 percent of the gasoline pool using E10 gasohol. The new second-generation ethanol accounts for 2 percent of the initial total demand of the domestic motor gasoline class. The construction of the second-generation ethanol production results in a $1,443.71 million growth in total industrial output, where the direct effect accounts for $490.01 million. In addition, increased second-generation ethanol production adds an additional $5.57 billion to total sectoral output, or 0.15 percent of initial total industrial output. The contribution of second-generation ethanol and gasohol industrial sectors to the total industrial output is estimated to be $5.87 billion (0.16 percent in total output). The total employment increases by 2,483 jobs, while the GDP grows by $74.04 million (0.0039 percent). The new second-generation ethanol industrial sector generates $101.58 million more in GDP. Moreover, the change in sectoral output is significant in the manufacturing sector. In addition, a moderate increase in output is seen in the agricultural, forestry, fishing and hunting sector. The mining sector sees a modest decrease in their industrial output. The industries affected the most is the result of an initial reduction in output in the petroleum refineries industrial sector and its forward linkages. For that reason, the advanced mandate has a considerable negative effect on the output in the petroleum refineries industrial sector and a modest impact on its upstream industries (e.g., oil and gas extraction industrial sector and oil sand extraction industrial sector). The impact analysis shows an increase in industrial output ($3,921.65 million), GDP ($44.07 million), and employment (1,011 jobs) when 2 percent of the motor gasoline is further replaced by second-generation ethanol through an advanced mandate.

In sum, although there is a slight reduction in animal production and its downstream industries because of feedstock competition, the economy benefits from second-generation biofuel production overall and becomes less dependent on imported ethanol or gasoline. The import substitution policy leads to a larger domestic economic stimulus without replacement of gasoline and first-generation ethanol. It also leads to less pressure on the mining sector during the adjustment process. On the other hand, the advanced mandate makes Canada more independent of gasoline imports, as well as the first-generation substitution policy in comparison to the import substitution policy.

Considering GHG emissions, the import substitution policy increases aggregated GHG emissions (0.23 Mt CO_2eq) at the stage of combustion and production. The main reason is more domestic second-generation ethanol production is generated as compared to the previous ethanol imports. However, the production of cellulosic ethanol might reduce total GHG emissions substantially if it uses agricultural residues. The first-generation substitution policy reduces GHG emissions modestly during the production and combustion process, but the reduction rate is even higher for second-generation ethanol. Moreover, it will significantly contribute to GHG reduction if the reduced first-generation ethanol came from feedstock farmed on cropland derived from grassland. As a result, for certain regions the first-generation substitution policy will contribute the largest GHG emission reductions. However, without land use change, advanced mandate performs the best (a reduction of 1.93 Mt CO_2eq) with the lowest blending rate (2 percent).

If the existing land use and management are sustainable, first-generation substitution policy and the advanced mandate will contribute to the GHG emissions reduction target, especially the advanced mandate. However, if current land use is not sustainable, the two substitution policies, especially the first-generation substitution policy, will result in more GHG savings in comparison with the advanced mandate. The environmental effect of these policies depends on the current situation of land use and management. With the increase in the blending rate of second-generation ethanol, the GHG emission reductions are higher. For this reason, this study suggests increasing the blending rate of second-generation ethanol.

In Scenario 3, the implementation of an E45 first-generation ethanol mandate or E35 second-generation ethanol mandate was estimated. These mandates would achieve the GHG emission reduction goal for `the transportation sector in 2030. Though this policy is very ambitious, it might not be achieved by 2030, but could be achieve by 2040. Policymakers can decide the policy mix according to the priority of objectives.

6.4 Limitations of the Study

There are several limitations to this study. One is the use of a single feedstock, corn residues. The previous studies have shown multiple feedstocks might lead to a higher economic stimulus with less disturbance in the feedstock market and its downstream or upstream sectors. However, detailed data for technology with multiple feedstocks was unavailable.

The Canadian SUTs for the year 2017 were applied at the detailed level. However, between 2017 and 2020, the national industrial structure might have evolved, notably in industries with considerable technological change. The estimated impacts were based on the 2017 technological structure. The 2017 SUTs do not reflect the most up-to-date technology coefficient and thus cause a certain amount of error in the estimates.

The 2017 Canadian SUTs had limited transportation fuel disaggregation. The fuel ethanol is incorporated into the motor gasoline class. Therefore, the first-generation ethanol is supplied by the basic chemical manufacturing industrial sector. The combination of these industries might negatively influence the precision of the estimates. For example, when using the RAS method to reconcile the SUTs, the forward linkages of the first-generation ethanol industrial sector may be spread to upstream industries of the petroleum refineries industrial sector because fuel ethanol is merged into the motor gasoline class.

The RAS-type method is likely to lead to errors in estimation with certain unrealistic forecasts. The iteration process may not converge, especially for a sparse initial matrix with numerous zeros, so the remaining nonzero elements could not adjust to the entire burden of change. Additionally, the RAS method makes arbitrary adjustments to technological coefficients which might conflict with technological advances or market forces.

Furthermore, the data used to construct the cost structure of the second-generation ethanol industrial sector relied on a series of assumptions. First, the prices of ethanol and gasoline are the same. Second, the second-generation ethanol industrial sector applies the same latent technology in the target plant. Third, it is assumed that constant returns to scale occur in this industry. Errors could have occurred during the construction of the cost structure given the assumptions made on the model and data.

Finally, in the second policy scenario, the advanced biofuel mandate is simulated. Although the gasohol industrial sector and product are useful to carry out the mandate, it might induce overestimation of the change in total output and employment, since gasohol includes both gasoline and ethanol.

6.5 Future Research

When the data is available for the cost structure of second-generation ethanol from various feedstock, corresponding research can be conducted to quantify the macroeconomic effects of the new second-generation bioethanol industrial sector. Such technology is more likely to represent the potential performance of this industrial sector.

In addition, this study suggests separating ethanol fuel from the motor gasoline class and further classify ethanol fuel into first-generation ethanol and second-generation ethanol if the data is available. This will improve the precision of the calculation.

Finally, a biofuel policy mix may have a distinct effect when compared to a single policy. Future research is needed to simulate several complementary biofuel policies and mandates. According to previous research, the import substitution policy might offset the effect of the advanced mandate, while a carbon tax might be ineffective when the mandate is implemented and indeed increases the biofuel demand in certain instances.

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Appendix

Appendix A Major Cellulosic Ethanol Plants Worldwide[7]

Project Owner (Project name)	Startup (status)	Technology[8]	Feedstock	Output	Location
GranBio[9] (Bioflex 1)	2014 (operational)	Fermentation, TRL 8	Sugarcane bagasse and straw	cellulosic ethanol (62,000 t/y)	Sao Miguel, Alagoas, Brazil
Longlive Bio-technology Co. Ltd. (Longlive)	2012 (operational)	Fermentation, TRL 8	Corn cob	cellulosic ethanol (60,000 t/y)	Yucheng, Shandong, China
POET-DSM Advanced Biofuels (Project Liberty)[10]	2014 (operational)	Fermentation, TRL 8	agricultural residues	cellulosic ethanol (75,000 t/y), FT liquids (25), biogas	Emmetsburg, Iowa, United States
Quad-County Corn Processors (Quad Country Biorefionery)	2014 (operational)	Fermentation, TRL 8	corn kernel fibre	cellulosic ethanol (6,000 t/y)	Galva, iowa, USA
Raizen Energia	2015 (operational)	Fermentation, TRL 8	sugarcrop residue	cellulosic ethanol (31,600 t/y)	Costa Pinto, Brazil
SEKAB (Biorefinery Demo	2004	PVC5, TRL 8	primary wood chips; sugarcane	cellulosic ethanol	Ornskoldsvik, Sweden

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[7] IEA Bioenergy. Task 39, Database on Facilities for the Production of Advanced Liquid and Gaseous Biofuels for Transport (2021) http://demoplants.bioenergy2020.eu/ , Accessed 27th Jan 2021

[8] TRL 4-5 Pilot; TRL 6-7 Demonstration; TRL 8 First-of-a-kind commercial; TRL 9 Commercial. PVC5: Alcohol fuels from cellulosic sugars.

[9] GraalBio announced plans to build at least five commercial-scale cellulosic ethanol plants in Brazil using Beta Renewables' PROESA process and Chemtex services.

[10] Integrated technology package that converts corn crop residue to cellulosic bioethanol to third parties, as well as the other 26 existing corn ethanol plants in POET's network. the process makes use of corn stover that passes through the combine during harvest. They use approximately **25%** of the material, leaving about **75%** on the ground for erosion control, nutrient replacement and other important farm management practices.

Plant)	(operational)		bagasse, wheat, corn stover, energy grass, recycled waste etc. (2 t/d)	(160 t/y)	
St1 (Etanolix[11] Jokioinen)	2011 (operational)	Fermentation, TRL 9 (St1 Biofuels)	food industry waste and process residues, bread waste (24,000 t/y)	ethanol (7,000 t/y), co-product: 30,000 m3 (17% Dry Solids) liquid animal feed	Jokioinen, Finland
St1 (Etanolix Gothenburg)	2015 (operational)		food industry waste and process residues, bread waste (20,000 t/y)	ethanol (4,000 t/y), co-product: 20,000 m3 (9% Dry Solids) liquid animal feed	Gothenburg, Sweden
St1 (Etanolix Vantaa)	2009 (operational)		bakery waste and process residues, bread waste (5,500 t/y)	ethanol (1,000 t/y); co-product: 10,000 m3 (10% Dry Solids) liquid animal feed or feed for biogas plant	Vantaa, Finland
St1 (Etanolix Lahti)					Lahti, Finland
St1 (Etanolix Hamina)	2008 (operational)				Hamina, Finland
American Process (Alpena Biorefinery)	2012 (operational)	Fermentation; TRL 8	hardwood residue	cellulosic ethanol (2,100 t/y); other (6,000 t/y)	Alpena, Michigan, USA
AustroCel Hallein (biorefinery)	2020 (operational)	PVC5, TRL 8; Borregaard technology	sulfite spent liquor (SSL, 33% dry content) from spruce wood pulping (600,000 t/y)	cellulosic ethanol (30,000 t/y)	Hallein, Austria
Borregaard Industries AS (ChemCell Ethanol)	1938 (operational)	PVC5, TRL 9; Borregaard technology	sulfite spent liquor (SSL, 33% dry content) from spruce wood pulping (400,000 t/y)	cellulosic ethanol (15,800 t/y)	Sarpsborg, Norway

[11] Etanolix®-plant is developed and delivered by St1 Biofuels. Etanolix plants are designed to produce advanced ethanol form food industry waste and residue. Main process units are: feedstock receiving and pretreatment, enzymatic hydrolysis, fermentation and ethanol distillation. Main by-product is stillage to be used as animal feed or feed for biogas plant.

Domsjoe Fabriker (Domsjoe Fabriker)	1940 (operational)	PVC5; TRL 8	organic residues and waste streams (sugars from pulping of lignocellulose)	cellulosic ethanol (19,000 t/y)[12]	Ornskoldsvik, Sweden
Henan Tianguan Group (Henan 2)	2011 (operational)	Fermentation, TRL 8	lignocellulosics	cellulosic ethanol (30,000 t/y)	Nanyang, Henan, China
Clariant [13] [14] (Clariant Romania)	2021 (under construction)	PVC5, TRL 8	wheat and other cereal straw (250,000 t/y)		Podari, Romania
Eta Bio (Cellulosic Ethanol Plant Clariant Technology)	(planned)	Fermentation, TRL 8	Wheat straw (250,000 t/y)	cellulosic ethanol (50,000 t/y) [Clariant "sunliquid" technology]	General Toshevo, Bulgaria
Enviral (Enviral's Leopoldov Site)	(planned)	Fermentation, TRL 9	lignocellulosics		Leopoldov, Slovakia
St1 (Cellulonix[15] Follum)					Ringerike, Norway
St1 (Cellulonix Pietarsaari)	2024 (planned)	Fermentation, TRL 8, St1 technology	sawdust (450,000 t/y)	cellulosic ethanol (40,000 t/y); By-products are terpentine, wood vinasse, lignin, furfural, biogas and CO2	Pietarsaari, Finland
St1 (Cellulonix Kajaani 2)					Pietarsaari, Finland

[12] The ethanol is produced as a by-product of cellulose production (just like Borregaard)

[13] Clariant. 2017. Clariant and Enviral Announce First License Agreement on Sunliquid® Cellulosic Ethanol Technology. https://www.clariant.com/en/Corporate/News/2017/09/Clariant-and-Enviral-announce-first-license-agreement-on-sunliquid-cellulosic-ethanol-technology

[14] Clariant. 2017. Clariant to Build Flagship Sunliquid® Cellulosic Ethanol Plant in Romania. https://www.clariant.com/en/Corporate/News/2017/10/Clariant-to-build-flagship-sunliquid-cellulosic-ethanol-plant-in-Romania

[15] Cellunolix®-plant is developed and delivered by St1 Biofuels. Cellunolix biorefineries are designed to produce advanced ethanol and various other products from soft wood saw dust. Main process units are: feedstock receiving and pretreatment, enzymatic hydrolysis, fermentation and ethanol distillation. By-products are terpentine, wood vinasse, lignin, furfural, biogas and CO2.

Sainc Energy Limited (Cordoba)	2020 (planned)	PVC5, TRL 8	lignocellulosics	cellulosic ethanol (25,000 t/y); lignin	Villaralto, Spain
INA (ethanol)	planned	PVC5, TRL 8	Miscanthus, wheat straw	cellulosic ethanol (55,000 t/y)	Sisak, Croatia
ORLEN Poludnie (part of ORLEN GROUP) (Jedlicze Site)	planned	Fermentation, TRL 9	wheat straw	cellulosic ethanol (25,000 t/y)	Jedlicze, Powiat, Poland
Anhui Guozhen Group and Chemtex Chemical Engineering (Fuyang project)	2020 (planned)	Fermentation; TRL 9	wheat straw and corn stover	cellulosic ethanol (50,000 t/y) (Clariant´s sunliquid® cellulosic ethanol technology)	Fuyang, Anhui province, China
Versalis[16] (Crescentino restart)	2020 (planned)	PVC5; TRL 8[17]	wheat straw, rice straw, arundo donax, poplar (270,000 t/y)	cellulosic ethanol (40,000 t/y)	Crescentino, Italy
Beta Renewables (Energochemica)[18]	2017 (on hold)	Fermentation; TRL 8	agricultural residues	cellulosic ethanol (55,000 t/y)	Strazske, Slovakia
Beta Renewables (Alpha)	2018 (on hold)	Fermentation; TRL 8	energy grasses	cellulosic ethanol (60,000 t/y)	Clinton, North Carolina, USA
Abengoa Bioenergy Biomass of Kansas, LLC (commercial)	2014 (idle)	Fermentation; TRL 8	corn stover, wheat straw, switch grass (320,000 t/y)	cellulosic ethanol (75,000 t/y); power (electricity) (25)	Hugoton, Kansas, USA
DuPont (Commercial facility Iowa)	2016 (idle)	Fermentation; TRL 8	corn stover	cellulosic ethanol (82,672 t/y)	Iowa, Nevada, USA

[16] It is the former Beta Renewables/Biochemtex facility.

[17] Enzymatic conversion of selected Biomasses. Pretreatment, handling of pre-treated material and hydrolysis done in equipment specifically designed.

[18] duplicating Crescentino facility

Appendix B Major Cellulosic Ethanol Plant in Canada[19]

Name	Startup (Status)	Technology	Feedstock	Output	Location
Iogen Corporation (demo)	operational	Fermentation, TRL 6-7	wheat, barley and oat straw; corn stover, sugar cane bagasse and other agricultural residues (30 t/d)	cellulosic ethanol (1,600 t/y)	Ottawa, ON, Canada
Lignol (pilot)[20]	2009 operational	Fermentation, TRL 4-5	sugarcane bagasse	cellulosic ethanol (30 t/y)	Burnaby, BC, Canada
Iogen (Iogen)	cancelled	Fermentation, TRL 4-5 Pilot	agricultural residues	cellulosic ethanol (1,443 t/y)	Saskatoon, SK, Canada
Mascoma (commercial)	cancelled	Fermentation, TRL 8[21]	wood	cellulosic ethanol (60,125 t/y)	Drayton, AB, Canada
Woodland Biofuels (demo)	2013 operational	Fermentation, TRL 6-7	wood waste	ethanol (601 t/y)[22]	Sarnia, ON, Canada
Enerk[23] (Westbury commercial demonstration facility)	2009 operational	Fuel Synthesis, TRL 6-7	Treated wood (i.e., decommissioned electricity poles, and railway ties), wood waste and MSW (48 t/d)	cellulosic ethanol (4,000 t/y); methanol (1,000), various chemicals	Westbury, QC, Canada

[19]_IEA Bioenergy. Task 39, Database on Facilities for the Production of Advanced Liquid and Gaseous Biofuels for Transport (2021) http://demoplants.bioenergy2020.eu/ , Accessed 27th Jan 2021

[20] Facility moved to Burnaby from Vancouver. Pilot operated on a campaign basis. Company now in receivership (August 2014)

[21] Lallemand bought the yeast work/patents and Renmatix the pretreatment patents and equipment

[22] Announced target is 53 Mgy commercial scale. Commissioned in 2012-13. Seems to be operating but on short campaigns.

[23] Enerkem develops biofuels and chemicals from waste. with its proprietary thermochemical technology, Enerkem converts abundantly available municipal solid waste (mixed textiles, plastics, fibers, wood and other non-recyclable waste materials) into chemical-grade syngas, and then methanol, ethanol and other chemical intermediates that form everyday products. It initiated production (bio-methanol) in 2015; ethanol module currently being added; ethanol production started in 2019

CORE Biofuel (Demo plant)	2014 idle	Gasification, TRL 6-7	wood waste (sawmill waste & roadside residues)	cellulosic ethanol (53,511 t/y)	Houston, BC, Canada
Woodland Biofuels (pilot)	2011 operational	Fermentation, TRL 4-5	wood waste	ethanol (60 t/y)	Sarnia, ON, Canada
Lignol Innovations Ltd. (pilot)	2009 operational	Fermentation, TRL 4-5 [24]	hardwood & softwood residues (1 t/d)	cellulosic ethanol (30 t/y); lignin	Burnaby, BC, Canada
Enerkem Alberta Biofuels LP (Edmonton Waste-to-Biofuels Project)[25]	2014 operational	Fuel Synthesis, TRL 8	post-sorted municipal solid waste (MSW) (100,000 t/y)	ethanol (30,000 t/y), methanol, various chemicals	Edmonton, AB, Canada
Vanerco (Enerkem & Greenfield Ethanol) (Varennes Cellulosic Ethanol)	under construction	Fuel Synthesis, TRL 6-7	sorted industrial, commercial and institutional waste	ethanol (30,000 t/y)	Varennes, PQ, Canada
Tembec Chemical Group (Synthesis Tembec Chemical Quebec)	operational	Gasification, TRL 6-7	spent sulphite liquor feedstock	cellulosic ethanol (13,000 t/y)	Temiscaming, QC, Canada
Enerkem (Synthesis Enerkem Sherbrooke)	2003 operational	Gasification, TRL 4-5	municipal solid waste, wood chips, treated wood, sludge, petroleum coke, spent plastics and wheat straw	cellulosic ethanol (375 t/y); methanol (475 m3/y); SNG	Sherbrooke, QC, Canada
Greenfield Ethanol (Greenfield)	2010 operational	Fermentation, TRL 4-5	lignocelluloses	cellulosic ethanol (30 t/y)	Chatham, ON, Canada

[24] Pilot (estimated capacity 10K gpy) open Q2 2009. Facility moved to Burnaby from Vancouver. Pilot operated on a campaign basis. Company now in receivership (August 2014)

[25] This project is still seeking funding as of September 2014

Appendix C Policy Scenario 1: Estimation of Total Revenue for 2G Ethanol Sector

Ethanol production in 2017 (ML)	822.50
Ethanol basic price ($/L)	0.80
Total value of ethanol production in 2017 ($M)	661.56
Electricity production (million kW-h)	247.20
Electricity selling price ($/kW-h)	0.06
electricity value ($M)	13.78
Total revenue ($M)	675.35

Appendix D Policy Scenario 1: Margin Value Matrix for Ethanol (M$)

	wholesale margins – farm products	wholesale margins – machinery, equipment and supplies	wholesale margins – miscellaneous products	grain storage margins	air freight transportation services margins	rail freight transportation services margins	water freight transportation services margins	road transportation services for specialized freight margins	water transportation support, maintenance and repair services margins	road transportation support services margins	freight transportation arrangement and customs brokering services margins	other transportation support services margins	Taxes on products
crop residue	19.43	0.00	0.00	5.47	0.00	9.70	0.07	10.28	0.04	0.06	0.36	0.06	0.00
Electricity	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.01
Water delivered by water works and irrigation systems	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Sewage and dirty water disposal and cleaning services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Steam and heated or cooled air or water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39
Other basic inorganic chemicals and nuclear fuel	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Basic organic chemicals, n.e.c.	0.00	0.00	8.40	0.00	0.00	0.37	0.01	6.21	0.00	0.02	0.14	0.04	0.23
Other industry-specific machinery	0.00	35.09	0.00	0.00	0.00	0.04	0.00	0.91	0.00	0.03	0.17	0.05	0.79
Total	19.43	35.09	8.41	5.47	0.00	10.12	0.08	17.43	0.05	0.12	0.68	0.15	2.46

Appendix E Policy Scenario 1: Cost Structure of 2G Ethanol Sector (M$)

Inputs in the use table	**Basic Price**	**Margin& Tax**	**Purchaser**
Crop residue	149.14	45.47	194.61
Electricity	12.10	1.01	13.11
Water delivered by water works and irrigation systems	4.14	0.03	4.18
Sewage and dirty water disposal and cleaning services	42.78	0.00	42.78
Steam and heated or cooled air or water	24.52	0.39	24.91
Other basic inorganic chemicals and nuclear fuel	0.30	0.04	0.34
Basic organic chemicals, n.e.c.	110.32	15.43	125.75
Other industry-specific machinery	104.03	37.10	141.13
Wholesale margins - farm products	19.43	-	-
Wholesale margins - machinery, equipment and supplies	35.09	-	-
Wholesale margins - miscellaneous products	8.41	-	-
Air freight transportation services	0.00	-	-
Rail freight transportation services	10.12	-	-
Water freight transportation services	0.08	-	-
Road transportation services for specialized freight	17.43	-	-
Water transportation support, maintenance and repair services	0.05	-	-
Road transportation support services	0.12	-	-
Freight transportation arrangement and customs brokering services	0.68	-	-
Other transportation support services	0.15	-	-
Grain storage	5.47	-	-
Tax on product	2.46	-	-
Gross operating surplus	107.40	-	107.40
Taxes on production	2.32	-	2.32
Wages and salaries	18.81	-	18.81
Total	675.35	99.47	675.35

Appendix F Policy Scenario 2: Estimation of Total Revenue for 2G Ethanol Sector

Ethanol production in 2017 (ML)	635.28
Ethanol basic price ($/L)	0.80
Total value of ethanol production in 2017 ($M)	510.98
Electricity production (million kW-h)	190.94
Electricity selling price ($/kW-h)	0.06
electricity value ($M)	10.64
Total revenue ($M)	521.62

Appendix G Policy Scenario 2: Margin Value Matrix for Ethanol (M$)

	wholesale margins – farm products	wholesale margins – machinery, equipment and supplies	wholesale margins – miscellaneous products	grain storage margins	air freight transportation services margins	rail freight transportation services margins	water freight transportation services margins	road transportation services for specialized freight margins	water transportation support, maintenance and repair services margins	road transportation support services margins	freight transportation arrangement and customs brokering services margins	other transportation support services margins	Taxes on products
crop residue	15.00	0.00	0.00	4.22	0.00	7.49	0.05	7.94	0.03	0.05	0.28	0.05	0.00
Electricity	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.78
Water delivered by water works and irrigation systems	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Sewage and dirty water disposal and cleaning services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Steam and heated or cooled air or water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
Other basic inorganic chemicals and nuclear fuel	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Basic organic chemicals, n.e.c.	0.00	0.00	6.49	0.00	0.00	0.29	0.01	4.80	0.00	0.02	0.11	0.03	0.18
Other industry-specific machinery	0.00	27.11	0.00	0.00	0.00	0.03	0.00	0.71	0.00	0.03	0.13	0.04	0.61
Total	15.00	27.11	6.49	4.22	0.00	7.82	0.06	13.46	0.04	0.09	0.52	0.12	1.90

Appendix H Policy Scenario 2: Cost Structure of 2G Ethanol Sector (M$)

Inputs in the use table	**Basic Price**	**Margin& Tax**	**Purchaser**
Crop residue	115.19	35.12	150.31
Electricity	9.35	0.78	10.13
Water delivered by water works and irrigation systems	3.20	0.03	3.23
Sewage and dirty water disposal and cleaning services	33.04	0.00	33.04
Steam and heated or cooled air or water	18.94	0.30	19.24
Other basic inorganic chemicals and nuclear fuel	0.23	0.03	0.26
Basic organic chemicals, n.e.c.	85.21	11.91	97.12
Other industry-specific machinery	80.35	28.65	109.00
Wholesale margins - farm products	15.00	-	-
Wholesale margins - machinery, equipment and supplies	27.11	-	-
Wholesale margins - miscellaneous products	6.49	-	-
Air freight transportation services	0.00	-	-
Rail freight transportation services	7.82	-	-
Water freight transportation services	0.06	-	-
Road transportation services for specialized freight	13.46	-	-
Water transportation support, maintenance and repair services	0.04	-	-
Road transportation support services	0.09	-	-
Freight transportation arrangement and customs brokering services	0.52	-	-
Other transportation support services	0.12	-	-
Grain storage	4.22	-	-
Tax on product	1.90	-	-
Gross operating surplus	82.96	-	80.99
Taxes on production	1.79	-	3.76
Wages and salaries	14.53	-	14.53
Total	521.62	76.83	521.62