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Assessing the long-term climate change mitigation potential of alternative agri-food consumption patterns with the TIMES-Canada model

par

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Résumé

Dans ce mémoire, nous testons l'hypothèse qu'une consommation agroalimentaire nationale comprenant une plus faible concentration de produits animaliers diminuerait les émissions de gaz à effet de serre et serait un moyen envisageable afin d'atténuer les changements climatiques. Cette hypothèse est vérifiée à l'aide du modèle TIMES-Canada qui est un modèle d'optimisation représentant les différents secteurs d'énergie du Canada. Cette approche permet d'analyser les données environnementales, gaz à effet de serre et consommation d'énergie, liées à la consommation agroalimentaire sur un horizon temporel de vingt ans (2007 à 2030) et de dresser un portrait compréhensif du potentiel d'atténuation d'une modification de la consommation agroalimentaire canadienne. Nos résultats suggèrent qu'une diminution de la consommation de produits animaliers diminuerait considérablement les émissions de gaz à effet de serre et la consommation d'énergie du secteur de l'agriculture, mais que le potentiel d'atténuation « nationale » est faible si l'on regarde l'effet sur les émissions et la consommation d'énergie totales au Canada.

Mots-clés : Changement climatique; Consommation agroalimentaire; Modèle d'énergie; Optimisation linéaire.

Abstract

In this thesis, we test the hypothesis that a national agri-food consumption pattern composed of less meat and dairy products reduces greenhouse gas emissions and is a viable strategy for climate change mitigation. This hypothesis is verified with the use of the TIMES-Canada energy model, which is a detailed optimization model of Canada's different energy sectors. This approach allows for a long-term analysis (2007 to 2030) of environmental effects, greenhouse gas emissions and energy consumption, tied to different national consumption patterns and provides a comprehensive portrait of the mitigation potential of Canadian agri-food consumption pattern modification. Our results suggest that decreasing the Canadian consumption of meat and dairy products significantly decreases greenhouse gas emissions and energy consumption in the agricultural sector; however, the overall mitigation potential, in terms of total Canadian emissions and energy consumption, via the agricultural sector, is weak.

Keywords: Climate Change; Agri-food Consumption; Energy model; Linear optimization.

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List of Abbreviations

- BAU: Business-as-usual
- CH_4: Methane
- CO_2e : Carbon dioxide equivalent emissions
- G&O: Grains and oilseeds
- GDP: Gross domestic product
- GHG: Greenhouse gas
- Kcal: kilocalories
- Kg: Kilogram
- LCA: Life cycle analysis
- MARKAL: Market allocation model
- MJ: Megajoules
- MT: Megatonne
- N_2O: Nitrous Oxide
- NGLs: Natural gas liquids
- PJ: Petajoules
- RES: Reference energy system
- TIMES: The integrated Markal-EFOM System

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Note to the reader

Chapter 4 of the thesis consists of a research article co-written with Olivier Bahn, Jean-Philippe Waaub and Kathleen Vaillancourt (Meat, dairy and climate change: Assessing the long-term mitigation potential of alternative agri-food consumption patterns in Canada). The 'Methodology' section is principally the work of Oliver Bahn, Jean-Philippe Waaub and Kathleen Vaillancourt. The 'Introduction', 'Data', 'Scenario characterization', 'Results' and 'Conclusion' sections are principally the work of Erik Frenette.

Chapter 1

Introduction

1.1 Climate change and agriculture

Climate change has emerged as a critical contemporary environmental problem and there has been increased pressure on policy makers to implement effective means of climate change mitigation and/or adaptation. Up to now, the main focus has been put in exploring means of mitigation, principally for the economic sectors with the highest emission levels in order to minimize greenhouse gas (GHG) emissions.

Agriculture accounted for 13.5% of global emissions in 2006, which is slightly more than the transportation sector's contribution of 13.1% (IPCC, 2007). Furthermore, the majority of agricultural emissions are tied to livestock related activities (Garnett, 2009). Therefore, the reduction of meat consumption has been put forward as a viable mitigation option and has been recommended by the IPCC. However, global meat consumption is actually rising. From 1995 to 2011, global per capita meat consumption increased by 15% to 42.3 kg per person (Worldwatch Institute, 2011) and dairy has been increasing at an average rate of 1.5% per year for the same time-span (Dairy co, 2012).

In Canada, agricultural activities account for about 2% of total energy demand (Statistics Canada, 2011) and 8% of all Canadian GHG emissions (Environment Canada, 2012). Indeed, the agricultural sector totaled 56 megatonnes (MT) of CO_2 equivalent (CO_2e) emissions in 2010 and livestock production represented 59% of total emissions in the agricultural sector in 2010, without counting emissions from feed production (Environment Canada, 2012). Additionally, similar to the global trend, there is a projected increase in annual per-capita meat consumption from 49.35 kg per person in 2010 to 52.77 kg in 2020 (Agriculture and Agri-food Canada, 2005). For dairy products[1], there is a projected decrease in consumption from 80.19 kg per capita in 2010 to 77.38 kg per capita in 2020.

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[1] The 'Selected Dairy' category in the Agriculture and Agri-food Canada (2005) publication includes fluid milk, cheese, cream and ice cream.

Therefore, to achieve significant GHG emission reduction in the Canadian agricultural sector, the meat and dairy consumption trend would need to be reversed, possibly via a consumption reduction policy. However, there is a lack of information needed to assess the viability of such a policy. Our research aims to answer the following question: What is the impact of reducing meat and dairy product consumption on Canadian agricultural energy usage and GHG emissions?

Throughout the literature, meat and dairy consumption reduction is presented as a viable option for GHG emission reduction; see for instance: Environmental Working Group (2011), Carlsson-Kanayama and Gonzalez (2009), Eshel and Martin (2006), Pimentel and Pimentel (2003), and, Carlsson-Kanyama, Ekstrom and Shanahan (2003), Carlsson-Kanyama and Faist (2000). Their conclusions are based on a life cycle analysis (LCA) approach where environmental impacts of products are assessed at all stages of production. Indeed, these articles estimate the input/output relationships between agri-food products, their energy usage and the resulting GHG emissions. Once these input-output relationships (i.e. MJ of energy or CO_2e emissions per kg of beef) are obtained, the authors are able to compare dietary changes by measuring the difference in aggregate energy input or GHG emissions output between different 'meals' or consumption patterns. The advantage of the LCA approach is the level of detail in the product-specific information it provides. However, this approach is considerably limited in analyzing dynamic, system wide implications of the food system due to the static nature of its results (Garnett, 2009).

This thesis considers an additional research step where these input/output relationships are implemented into a dynamic energy model to determine the resulting impact as part of the whole Canadian energy system. Therefore, the static input-output data is implemented into a dynamic optimization model in order to obtain results for progressive consumption changes at the national level.

Indeed, the contribution of this research is to estimate and analyze the effects of a meat and dairy product consumption reduction policy from a 2007 base year to 2030. Our approach consists in estimating the environmental impact of different agri-food consumption scenarios, which vary in their levels of livestock product consumption, and comparing them to a reference forecast of agricultural production from Statistics Canada (2011). The impact of these different agri-food consumption patterns is estimated using the TIMES-Canada model, a dynamic optimization energy model used to perform economic analysis of Canadian energy systems. The results from these scenarios are contrasted to illustrate the potential impact of a meat and dairy product consumption reduction policy.

1.2 Canadian context

Canada has its own set of economic characteristics that can make the application of such a policy difficult, especially when considering the lack of research aimed at assessing the viability of agri-food consumption reduction policies in general. Indeed, to our knowledge, this is the first research concerned with projecting the long-term impact, in terms of GHG emissions and energy usage, of such a policy. There are two main issues to applying such a policy for the Canadian context.

First, the livestock production industry is a significant part of Canada’s economy. In 2009, beef production contributed $23 billion to GDP (1.5% of total GDP for 2009) (The Beef Information Center, 2009). Also, the meat products industry employs 67 583 individuals and represents 2.5$ billion in total salaries and wages. It is also the biggest contributor to food industry manufacturing sales with $21.3 billion (Canada meat council, 2010). Therefore, when implementing a policy that is aimed at reducing meat consumption, economic repercussions must be carefully weighed. This reinforces the idea that any analysis pertaining to a projected decrease of livestock related production in Canada must be based on a long-term horizon with realistic and progressive consumption reduction forecasts.

Second, Canada is a net exporter of meat, meaning that livestock production is only partially determined by domestic meat consumption. Indeed, 378 525 tonnes of beef were exported in 2009 with 76% destined for the United States (Canada meat council, 2010). In other words, about 25% of beef production is tied to external demand, which cannot be affected by domestic consumption policies. Our research includes a scenario with a forecasted consumption reduction of meat and dairy products for all countries importing livestock products from Canada in order to highlight the effect trade has on the environmental impact tied to Canadian agricultural production.

Both of these Canada specific issues were implemented into our scenarios (chapter 4.5) and, thus, had an influence on our results and conclusions.

The existing literature on the environmental impact of meat consumption can serve as a general guideline for assessing the viability of certain measures; however, Canada specific research is essential in order to include the broader implications of such a policy. Therefore, one of the main contributions of this research is to elaborate Canada specific guidelines for meat and dairy consumption reduction policies.

2.1 Model and data

The impact of these different consumption patterns is estimated using the TIMES-Canada model; an energy model that is used to perform economic analysis on Canada's energy systems. The initial research phase consisted of augmenting the TIMES-Canada agricultural sector to allow for consumption pattern substitution analysis. Subsequently, the TIMES model was used to solve for the (partial) equilibrium for all energy sectors for our five different agri-food consumption scenarios.

Data from Statistics Canada was used to model the agriculture sector in TIMES-Canada. Historical energy use and production output for the Canadian agricultural sector was used to estimate the input-output relationships between energy, agri-food production and GHG emissions. Furthermore, an energy use survey performed by Statistics Canada was used to disaggregate the agricultural sector into nine different production sub-sectors: grains and oilseeds, beef, dairy, pork, poultry, eggs, fruit, vegetables and other (which includes all other agricultural production).

2.2 Thesis structure

The thesis is structured as follows. Chapter 2 presents the literature review. Chapter 3 introduces the TIMES modelling framework and the Canadian version of the TIMES model: Times-Canada. Chapter 4 consists of the article entitled: 'Meat, dairy and climate change: Assessing the long-term mitigation potential of alternative agri-food consumption patterns in Canada'. Section 4.1 is the article's introduction. Section 4.2 follows with the methodology. Section 4.3 describes the data used in the study. Subsequently, section 4.4 describes how the Canadian agricultural sector was modeled in TIMES-Canada. Section 4.5 describes the different scenarios used in the analysis and 4.6 presents the obtained results. Finally, section 4.7 concludes the article. The thesis ends with a short conclusion.

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Chapter 2

Literature review

2.1 Introduction

The objective of this chapter is to situate the present work within a precise research area and to compare it with similar works. This comparison will delineate the main differences, and highlight the strengths and weaknesses, of the different approaches found in the literature.

The following literature review is separated into two distinct research areas. First, the research centered on the LCA approach is presented as a comparison point for data collection, manipulation and estimation. More precisely, our means of obtaining energy and GHG emission coefficients, needed for our modelling of the Canadian agricultural sector, are compared with coefficients obtained through the LCA methodology. Second, the actual modelling of the Canadian agricultural sector in the TIMES-Canada model is compared with the only other TIMES study pertaining to assessing the climate change mitigation potential of the agricultural sector by Chiodi et al. (2012).

2.2 LCA approach

There are different ways of estimating the environmental impacts of agri-food consumption patterns; however, the most popular methodology found in the literature is that of life-cycle assessment (LCA). LCA is defined as ‘‘*a tool that can be used to evaluate the environmental load of a product, process, or activity throughout its life cycle*.’’ (Roy et al., 2009). The LCA methodology consists of, first, defining the activity bound and functional unit(s) to be used during the analysis and then establishing all the input/output processes required during the agri-food product’s life cycle. The input-output processes defined in LCA studies are analogous to ‘technologies’ in a TIMES model (see chapter 3.1). Indeed, this similarity is what allows for a direct comparison of the environmental coefficients found in the LCA literature with the coefficients used by the TIMES ‘technologies’ (see chapter 4.3 for the coefficient comparison). Therefore, our coefficients are benchmarked with coefficients obtained through the LCA approach to ensure that our results are based on realistic input-output processes (or 'technologies'), which are constructed from representative data.

This chapter will contextualize the LCA approach for environmental impact estimation by presenting key articles found in the literature. ''*LCA was traditionally applied to analyze industrial production systems, but has been adapted within the last 15 years to assess the environmental effects of agriculture*'' (Rural Industries Research and Development Corporation, 2009). Indeed, agricultural LCA is a relatively new approach and, consequently, a standardized methodology is lacking, making it difficult to determine which studies are, in fact, LCA studies. However, LCA studies do share some key methodological components: all LCA studies have an explicitly defined functional unit and activity bound. The following research papers share these methodological traits that tie them to the LCA approach and partake in a common research goal of assessing the environmental implications of meat consumption.

The agricultural LCA literature studying the environmental impact of meat consumption has a tendency to employ a very micro-oriented approach. First, researchers compile a list of food products with corresponding environmental impact coefficients such as kg of CO_2e greenhouse gas emissions per kg of the food product. Subsequently, they estimate the effect of a dietary change for one individual, usually when an individual substitutes meat for non-meat products in his diet. This approach has its strengths, such as the clarity of results. Indeed, being able to succinctly compare two different meals based on a single number representing environmental impact is useful. It provides practical and easily comprehensible information pertaining to the effects of agri-food consumption patterns. However, this micro-level analysis also has its limitations. Mainly, it does not provide information about the broader impact of such environmental policies; the provincial or national implications of policies aimed at reducing meat consumption. This gap in the literature and the corresponding contributions of this research will be further discussed following a review of its key articles.

First, the micro oriented approach is employed in the article by Pimentel and Pimentel (2003) where the research goal is to assess the sustainability of two different diets: meat-based and plant-based. The authors use the functional unit of fossil energy calories per calories of animal protein and bound the life-cycle activities at the farm gate; only agricultural activities are considered. Using data from the US department of agriculture (USDA), they estimate the coefficients for their functional units and assess the difference in energy usage between two per-capita diets. They find that both diets are unsustainable in the long run, but that the lacto-ovo-vegetarian diet has a preferable environmental impact.

Second, the research paper by Eshel and Martin (2006) employs data on fossil fuel usage per calorie of food products from Pimentel and Pimentel (2003) in order to estimate the environmental impact of five different diets: 'lacto-ovo', 'mean american', 'fish', 'red meat' and 'poultry'. The authors come to the conclusion that the difference, in terms of environmental impact, between a red meat diet and a plant based diet is equivalent to the difference between driving a Camry or a sports utility vehicle (SUV); the goal was to illustrate the importance of dietary choices by comparing the food industry to the transport industry.

The third article is by Carlsson-Kanyama and Faist (2001), which consists of the results from a data survey conducted by the authors in order to contribute to the micro-level LCA data for food products. They compiled a list of energy usage properties for 150 food items. The motivation was the lack of appropriate data available for agricultural LCA research. It is also interesting to note that this data has been used as the fundamental data for the two following research papers co-authored by Carlsson-Kanyama which are included in this review of the literature: Carlsson-Kanyama, Ekstromb and Shanahan (2002) and Carlsson-Kanyama and Gonzalez (2009). The gathered data originates from mixed sources such as: scientific journals, Swedish government publications and personal communications with agricultural or food processing representatives. The activity bound is cradle-to-grave, meaning all activities until the product is consumed, and the functional unit used is megajoules (MJ) of energy per kg of food product.

Fourth, we have the subsequent article by Carlsson-Kanyama (2002). This publication builds on Carlsson-Kanyama's data survey and presents results for 150 food items divided into 19 categories. The functional unit is MJ of energy per kg of food product and the activity bound is the complete life-cycle. The research goal is to use this data to compare two daily diets, which vary in the amount of energy needed to produce the included food products. The fundamental result is that the energy usage of diets can vary greatly. In their example, the daily quantity of MJ of life cycle inputs varies from 13MJ to 51MJ depending on the diet of a single individual. Another important conclusion: diets containing more meat, especially red meat, have higher life-cycle energy inputs.

The fifth paper is by Carlsson-Kanyama and Gonzalez (2009), the main difference with the previous Carlsson-Kanyama papers is the focus on GHG emissions instead of energy usage. Indeed, the functional unit has changed from MJ/kg of food product to kg CO_2e/kg of food product. The paper uses data from the Intergovernmental Panel on Climate Change to estimate the GHG coefficients for 22 food products. The authors proceed in comparing three different meal compositions in order to demonstrate the variability in the GHG emissions of different food products. The result is that the vegetarian meal is ten times less harmful to the environment that the beef meal. The authors conclude by stating: ‘‘*The analysis shows that changes toward a more plant-based diet could help substantially in mitigating emissions of GHGs.*’’ (Carlsson-Kanyama and Gonzalez, 2009, p.4)

The final research paper is by the Environmental Working Group (2011). The functional unit used is kg CO_2e per kg of food product and the activity bound is separated into two phases: agricultural processes and post-agricultural processes. The authors compile a list of 20 food products with their corresponding emission coefficients. The result is consistent with previous findings: animal food products have a considerably higher negative impact on the environment than non-animal food products.

These six key articles are summarized in table 1 accompanied by the functional unit and activity bound employed:

Table 1 - List of key articles from the litterature

Title	Authors	Year of publication	Functional Unit	Activity Bound
Meat eaters guide to climate change and health	Environmental Working Group	2011	Kg CO_2e / kg of food product	Agricultural and Post-Agricultural Life Cycle
Potential contributions of food consumption patterns to climate change	Carlsson-Kanyama and Gonzalez	2009	Kg CO_2e / kg food product	Complete Life Cycle
Diet, energy, and global warming	Eshel and Martin	2006	Kcal fossil energy / kcal animal protein	Agricultural Life Cycle
Sustainability of meat-based and plant-based diets and the environment	Pimentel and Pimentel	2003	Kcal fossil energy / kcal animal protein	Agricultural Life Cycle
Food and life cycle energy inputs: consequences of diet and ways to increase efficiency	Carlsson-Kanyama , Pipping Ekstromb, Shanahan	2002	MJ energy / kg food product	Complete Life Cycle
Energy use in the food sector: a data survey	Carlsson-Kanyama and Faist	2001	MJ energy / kg food product	Complete Life Cycle

It is important to note the lack of primary data in the literature. Indeed, Eshel and Martin (2006) employed the same data as Pimentel and Pimentel (2003). Also, the three articles by Carlsson-Kanyama are based on the same primary data. Therefore, an additional contribution of this thesis to the literature is to provide more primary data, which can be used for future agricultural LCA research.

2.3 Limitations of the LCA approach

The LCA approach has limited use for agri-food consumption policy design for several reasons. The studies estimating the environmental effect of a dietary change perform their estimation at the individual level (i.e.: what happens when one person changes their consumption pattern?). However, policy makers are often interested in provincial or national level studies, which require additional research components.

For example, estimation of the national level impacts of a meat consumption reducing policy must consider the fixed portion of the agricultural product demand composed of exports, which are exogenous consumption decisions; they are unaffected by domestic policies aimed at domestic consumption substitution. Additionally, total effect estimation must also consider the temporal constraints on agricultural production; the Canadian agricultural framework cannot be instantly modified to supply a new, meatless, diet. Finally, agricultural production is part of a dynamic energy demand system; constraining the demand for energy by limiting the production of energy intensive food products will have a system wide impact, which is not taken into consideration in the static analytical framework of the current approach. However, it is important to note that the economic effects taken into account by a dynamic energy model are limited to energy sectors. Indeed, estimating total economic effects of agri-food policies would require a general equilibrium model containing all economic sectors.

This research attempts to address some of these limitations in the following ways. First, this study employs a top-down approach in order to estimate the environmental coefficients of food products by starting with national level energy usage and GHG emission data and subsequently disaggregating until individual agricultural production technologies can be defined. This allows the analytical framework to be representative of national level activity as the micro level data is calibrated, by construction, with the macro level. Second, this data is integrated into the TIMES-Canada energy model allowing for a comprehensive analysis of the research question. The implications of a meat consumption reduction policy are assessed as part of the broad dynamic energy system represented by the model.

2.4 The TIMES approach

The only other TIMES model to implement a detailed agriculture sector with the goal of estimating the sector's climate mitigation potential is TIMES-Ireland (Chiodi et al., 2012). Similar to our methodology, TIMES-Ireland modified the original TIMES approach of modelling exogenous energy demand for the agricultural sector to an energy demand dependent on the consumption of physical units of agricultural products. Indeed they disaggregated the agricultural sector into six livestock production categories: non-dairy cattle, dairy cattle, sheep, swine, poultry, and others; and six crop production categories: pulses, potatoes, sugar beet, barley, oats, and wheat.

However, there is a significant difference in the research goal. The goal for Chiodi et al. (2012) is to measure the abatement potential of different agricultural technologies whereas our research goal is to analyze the effect of different consumption patterns using the same technologies. Therefore, TIMES-Ireland includes several technological possibilities for the production of the different agricultural products included in the model and the research is interested in evaluating the viability of investing in these different abatement technologies in order to achieve the different GHG emission goals included in their scenarios. Their conclusion is that GHG abatement measures in the agricultural sector are a cost-effective way of attaining GHG emission level goals; policymakers interested in climate change mitigation should not overlook the agricultural sector. Additionally, the GHG emission reduction goals are achieved through abatement technologies in the livestock sector, therefore, like our research, they are principally concerned with the climate change mitigation potential related to production of meat and dairy products.

2.5 Limitations of the TIMES approach

As previously stated, the TIMES approach for assessing the potential environmental impacts of a meat and dairy consumption reduction policy provides a more comprehensive analysis than the LCA approach. However, there are certain limitations on a TIMES model's capacity to represent reality. Principally, since the TIMES approach uses a scenario based analysis, the results are particularly sensitive to the elements determined by the scenario builder. For example, the scenario builder makes macro-economic assumptions to determine the evolution of useful energy demand and technological assumptions to determine the evolution of existing or future technologies. Indeed, the representativeness of the model's technologies and policy scenarios must be justified by accurate data and realistic assumptions. The justification of our data, data manipulations and underlying assumptions is presented in Chapter 4.

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Chapter 3

The model

3.1 Introduction

The mathematical formulas in this chapter are taken from Loulou (2008).

The TIMES model (an abbreviation for The Integrated MARKAL-EFOM System) is an economic model for local, national or multi-regional energy systems analysis. It is part of the MARKAL family of models, which originated in the 1970s. The model is used to make scenario-based projections for the energy sector of a particular economy by maximizing the total surplus (consumer and producer surplus). Additionally, it can be used for environmental policy assessments as GHG emissions are calculated for every process involved in attaining economic equilibrium. The model can be delineated into three main constituents: technologies, commodities and commodity flows.

First, technologies (or processes) represent all the input-output relations implemented in the model, which allow certain resources to be transformed into other resources. Technologies transform a resource into another by using energy and capital (investment costs, operations and maintenance, etc.). Second, commodities are all the resources, which are either produced or consumed by the different technologies to satisfy the different demands. Commodities consist of materials, energy services, energy carriers, monetary flows and greenhouse gas emissions. Last, commodity flows are the links between the different processes and technologies.

These three constituents are organized into an RES (Reference Energy System) which is a network diagram illustrating the relationships between the technologies, the commodities and the commodity flows starting with energy supplies and ending with final demand (see chapter 4.4 for the agriculture RES).

Due to the long-term projections needed for energy analysis (30+ years), the model employs a scenario-based approach for forecasts. This differs from forecasts provided by econometric models, which are better suited for shorter-term forecasts, the main difference being the assumptions included in the constructed scenario. In the TIMES model, in order for a scenario to be deemed complete it must include the following four components: The demand component, the supply component, the policy component and the techno-economic component.

3.2 The demand component

The demand component of the TIMES model is set exogenously. The base year of the analysis is set to the real useful energy demand observed in that particular year, while the demand for the subsequent years in the projection is based on demand drivers. Frequently used drivers for demand projections are: population, GDP, GDP per capita and the number of households. The useful energy demand is thus a function of one or more drivers and the determined elasticities of demand to these drivers:

$$D = \frac{d^{e+1}}{e+1} \times C \tag{1}$$

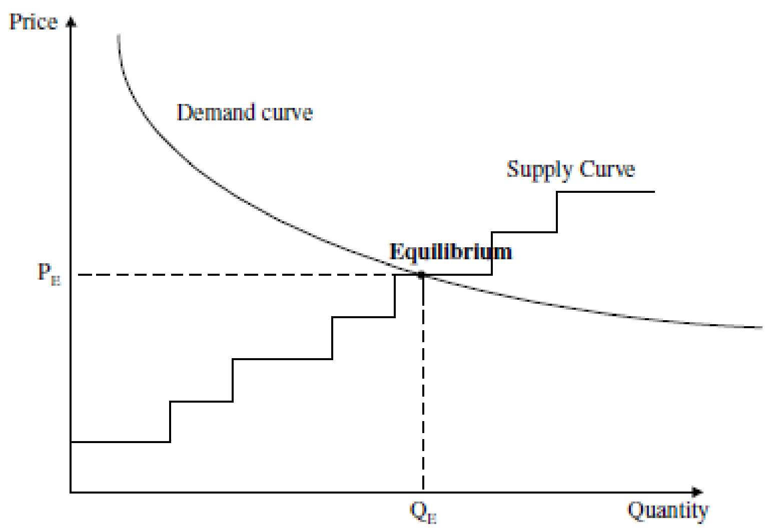
Where *d* is the demand driver, *e* is the elasticity and *C* is a constant representing the initial demand. The elasticities are set to establish a mathematical relationship between the different drivers. For instance, population growth can be used as a driver for agri-food consumption growth (the demand increase for agri-food products) and the relationship between population growth and agri-food demand growth can be set as directly related (elasticity of 1) or the modeler can set an elasticity of below or above one to meet the requirements of his or her scenario.

Additionally, the model includes own price elasticities of demand for the different energy commodities. This allows the model to adapt to different scenarios where the price of energy commodities varies. Therefore the demand component of the TIMES model is actually composed of demand curves that depend on their demand driver, the elasticity to this driver and the demand elasticity to its own price.

3.3 The supply component

The supply of energy stems from two sources. First, energy or material resources can be extracted domestically. Second, they can be acquired through trade. These two sources form multi-stepped supply curves where each step represents a different process for producing a commodity and the price incrementally increases with the quantity demanded, as more costly means of production must be employed. The model can then compute an equilibrium point for each commodity by calculating the intersection of the previously defined demand curves with the multi-step supply functions:

Figure 1 - TIMES equilibrium



3.4 The policy component

The inclusion of certain policies can have a significant impact on the result of the model. Different policies introduce different constraints on the model's optimization equation. For example, a limit on GHG emissions can provoke an increase in the number of 'green' technologies used by the model as the constraint on emissions favours 'cleaner' processes that were considered too costly in a BAU (business-as-usual) scenario.

In the agricultural sector, a constraint on GHG emissions could lead to agricultural producers using 'greener' processes for agri-food production (such as electric tractors). Also, an agri-food policy aimed at reducing meat and dairy consumption will constrain certain production activities, which we have seen in the literature review as being more energy intensive and emitting GHGs, leading to a different energy and environmental portrait compared to the BAU scenario.

3.5 The techno-economic component

The last constituent of a complete scenario is the group of technologies that are implemented and defined in the model. As previously described, these processes represent all the input-output relationships that are taken into consideration when maximizing total surplus and solving for the equilibrium. In the case of the agricultural sector, technologies were defined for eight production sub-sectors: grains and oilseeds, beef, dairy, poultry, eggs, pork, vegetables, and fruit. Each of these sub-sectors contains the different processes needed to transform the primary materials and energy into agri-food products. For example, the beef sub-sector contains processes for the transport, heating and lighting, machinery and other useful energy sources needed to produce metric tonnes of beef.

3.6 The TIMES basic assumptions

Before describing the mathematical components behind the TIMES equilibrium calculation, let us state the main economic assumptions the model is founded on.

First, the model assumes perfect market conditions. This allows the model to solve for equilibrium by employing the price equals marginal cost of production characteristic of a perfect market. Now, this assumption leads to results that may lack realism, especially for markets possessing natural monopoly characteristics, however, it does allow a normative view on how the energy sectors would be in equilibrium if the markets were efficient.

Second, the model assumes perfect foresight. This means that the model is aware of all of the variables for every year included in the projection at t_0; it cannot be 'surprised' by new technologies or undiscovered resources, characteristics which more closely reflect reality.

Third, the computation of the equilibrium point is based on the following Equivalence Principle: ''*The supply-demand equilibrium is reached when the total surplus is maximize*d''

(Loulou, 2008). Where one of the sufficient conditions is that the cross-price elasticities of any two energy forms are equal such that:

$$\frac{\partial Q_i}{\partial P_j} \times \frac{P_j}{Q_i} = \frac{\partial Q_j}{\partial P_i} \times \frac{P_i}{Q_j} \; for \;\; all \; i, j \tag{2}$$

In the TIMES model these conditions are satisfied by construction as the cross-price elasticities of commodities are assumed to be zero. Therefore, the equilibrium point can be found by simply solving for total net surplus.

3.7 The TIMES equilibrium

Now that we have outlined the three main constituents of the TIMES model and the four necessary components for a complete scenario analysis, we can take a look at the fundamental equations used by the model in determining the optimal equilibrium; the equilibrium which maximizes total surplus.

3.7.1 Demand functions

First, the demand curves in the TIMES model are defined as a function of some constant K_i (determined by the specified demand drivers) and a constant price elasticity relationship ${P_i}^{E_i}$ such that:

$$DM_i(p) = \; K_i \times {P_i}^{E_i} \tag{3}$$

Where DM_i represents the $i^{\,th}$ demand, P_i is the marginal cost of procuring the $i^{\,th}$ commodity, and E_i is the own price elasticity of demand. Now, we can define our reference case demand, the point that is exogenously determined by the modeller and known by the model, as being:

$$DM_i^{\,0}(p) = \; K_i \times {P_i^{\,0}}^{E_i} \tag{4}$$

Therefore we can rewrite the demand function as being solely dependent on prices and own price elasticity by dividing equation (3) by equation (4):

$$\frac{DM_i}{DM_i{}^0} = \left[\frac{P_i}{P_i{}^0}\right]^{E_i} \tag{5}$$

Subsequently, we can take the inverse of this function to obtain the price determining function:

$$P_i = P_i{}^0 \times \left[\frac{DM_i}{DM_i{}^0}\right]^{1/E_i} \tag{6}$$

3.7.2 Equilibrium

The first equilibrium case is a simplified scenario containing inelastic demands. In such a case the equilibrium point is found by solving the following minimization problem:

$$\min_x \ \boldsymbol{C} \times \boldsymbol{X} \tag{7}$$

$$s.t \quad \sum_k CAP_{k,i(t)} \geq DM_i(t), \qquad i = 1,..,I;\ t = 1,..,T \tag{8}$$

$$B \times X \geq b \tag{9}$$

where **X** is a vector of all commodity variables and C is the cost of producing each commodity. By minimizing their product, the model minimizes welfare loss or, in other words, total surplus. As shown by the equivalence theorem, a solution maximizing net total surplus results in the optimal equilibrium. This minimization problem is subject to, first, that all commodity *i* demands (from the first commodity *i* = 1 to the last which is denoted by *I*) 2are satisfied by stating that the sum of different *k* commodity capacities **CAP** for each type of commodity *i* be equal or superior to the demand for that commodity type DM_i. Additionally, this situation must hold for every time period *t* (from *t* = *1* to the last time period *T*). Also, the model must satisfy a set of arbitrary user determined constraints (or bounds) **B** and *b*. These constraints are established to obtain realistic results. For example, the modeller can specify that a consumer substitution of meat products by non-meat products be done gradually over every time period *t*, setting activity bounds to satisfy the given demand scenario.

The second equilibrium case is solving with elastic demands. Now, both the demand side and the supply side adjust to changes in price. Also, the prices charged by the supply side are equal to the marginal cost of producing the different commodities for the different demands DM_i as the model is based on a perfect competition assumption. From the cross price elasticity condition (2), we know that an equilibrium with elastic demands is reached when solving for net total surplus maximization:

$$\max_X \sum_i \sum_t \left[\mathrm{P_i}^0(\mathrm{t}) \times \left(\mathrm{DM_i}^0(\mathrm{t})\right)^{-1/\mathrm{E_i}} \times \int_{\mathrm{DM}_i(t)} \mathrm{q}^{1/\mathrm{Ei}}\, \mathrm{dq} \right] - \mathbf{C} \times \mathbf{X} \tag{10}$$

$$\mathrm{s.t} \quad \sum_{\mathrm{k}} \mathrm{CAP_{k,i(t)}} \geq \mathrm{DM_i}(\mathrm{t}), \qquad \mathrm{i} = 1,..,\mathrm{I};\ \mathrm{t} = 1,..,\mathrm{T} \tag{11}$$

$$\mathrm{B} \times \mathrm{X} \geq \mathrm{b} \tag{12}$$

where *q* represents marginal quantity demanded with respect to price for the corresponding commodity *i* and is integrated over the domain of demands for each commodity *i* at each time period *t*. Equation (10) represents the total net surplus and **DM** in equation (11) is no longer a fixed demand but a vector of variables. We can solve the integral in (10) and obtain the following maximization problem:

$$\max_X \sum_{\mathrm{i}} \sum_{\mathrm{t}} \left[\mathrm{P_i}^0(\mathrm{t}) \times \left(\mathrm{DM_i}^0(\mathrm{t})\right)^{-1/\mathrm{E_i}} \times \frac{\mathrm{DM_i}(\mathrm{t})^{1+\frac{1}{\mathrm{E_i}}}}{1 + \frac{1}{\mathrm{E_i}}} \right] - \mathbf{C} \times \mathbf{X} \tag{13}$$

$$\mathrm{s.t} \quad \sum_{\mathrm{k}} \mathrm{CAP_{k,i(t)}} \geq \mathrm{DM_i}(\mathrm{t}), \qquad \mathrm{i} = 1,..,\mathrm{I};\ \mathrm{t} = 1,..,\mathrm{T} \tag{14}$$

$$\mathrm{B} \times \mathrm{X} \geq \mathrm{b} \tag{15}$$

Therefore, the model solves for the total net surplus for all time periods *t* and all commodity types *i* and it is constrained to satisfy all exogenous demands for commodity types DM_i in all time periods *t*. Additionally, the model must satisfy a set of additional user defined constraints contained in (12).

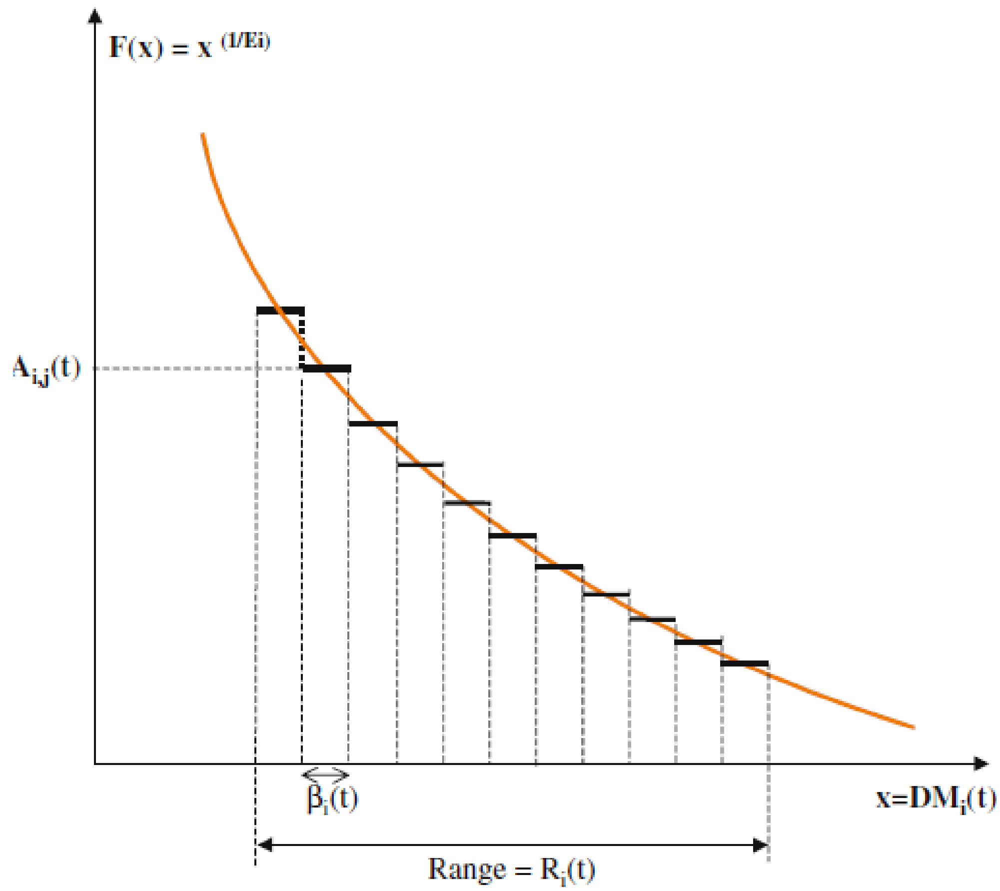
Lastly, since the model performs linear optimization, equation (10) must be linearly approximated by the model by employing a step function for the demand curves where the modeller defines:

1. A range $R_i(t)$ of realistic demand bounds (for example the reference demand $DM_i^0(t)$ plus or minus 50%)
2. The common width of the 'Steps' $\beta_i(t)$
3. A set of variables $A_{1,i}(t),\ A_{2,i}(t), \ldots, A_{n,i}(t)$, ordering each step with width $\beta_i(t)$. Therefore, the total demand for a particular commodity type i, $DM_i(t)$, can be redefined as the sum of segments $A_{j,i}(t)$.

$$DM_i(t) = DM(t)_{min} + \sum_{j=1}^{J} A_{j,i}(t) \tag{16}$$

The problem is now fully linearized and the equilibrium can be computed by the TIMES model. Figure 2 shows an example of a linearized demand curve with the corresponding variables of interest.

Figure 2 - Linearized Demand Curve



3.8 TIMES Canada

Although an 11-region MARKAL model of the Canadian energy system has been developed at GERAD in the past (see in particular Berger et al., 1992; Loulou et al., 1996; Kanudia and Loulou, 1999), a completely new database has been built to reflect the current situation on Canadian energy markets and to fit into the new TIMES modelling paradigm.

TIMES-Canada is now calibrated on to 2007 base year, using energy balances available at Statistics Canada (2007). It covers the energy system of the thirteen Canadian provinces and territories having their own reference energy system (RES), but linked together through energy, material as well as emission flows. For modelling and reporting purposes, four geographical regions have been created: i) WEST: Alberta (AB), British Colombia (BC), Manitoba (MB) and Saskatchewan (SK); ii) CENT: Ontario (ON) and Quebec (QC); iii) EAST: New Brunswick (NB), Newfoundland (NL), Nova Scotia (NS) and Prince Edward Island (PE); and iv) NORTH: Northwest Territories (NT), Nunavut (NU) and Yukon (YT).

The reference energy system of each province and territory is disaggregated as follows. In the energy supply side, two sectors are distinguished: electricity on the one hand, and supply of all other energy forms on the other. The former supply sector describes all central electricity and heat production, including combined heat and power and renewable potentials. The latter supply sector describes fossil fuel extraction, production and transformation processes, including petroleum refineries, as well as biomass potential. In the energy demand side, five sectors are considered: agriculture (AGR), commercial (COM), industrial (IND), residential (RSD) and transportation (TRA).

Our research is concerned with the agricultural sector. The standard representation of the agricultural sector in a TIMES model is simply the aggregation of the entire energy demanded by the sector, in MJ, for the different energy types. In order to allow for the analysis of the effects of substituting different consumption patterns with varying levels of meat and dairy products, the agricultural sector in TIMES-Canada was augmented to include production technologies for eight agricultural sub-sectors: grains and oilseeds, beef, dairy, poultry, eggs, pork, vegetables, and fruit (see chapter 4.4 for TIMES-Canada agriculture technologies).

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Chapter 4

Article

Meat, dairy and climate change: Assessing the long-term mitigation potential of alternative agri-food consumption patterns in Canada

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ABSTRACT

We use a newly developed bottom-up model of the entire Canadian energy system (TIMES-Canada) to assess the climate change mitigation potential of different agri-food consumption patterns in Canada. Besides a business-as-usual (baseline) scenario, we have constructed four different food policy scenarios to assess the viability of reducing Canadian meat and dairy consumption. Our policy scenarios progressively restrict the consumption of certain agri-food products until the year 2030 when they are reduced by one third of their initial consumption level and substituted by food products that are not constrained by the scenario. The reduction rate is the same for the four scenarios; however, the scope of the food products varies. Our first scenario reduces beef consumption, our second reduces beef, pork and poultry consumption, our third reduces all meat and dairy product consumption, and, our fourth scenario assumes that exports of all meat and dairy products are also reduced in the same manner. The viability of such policies is measured by comparing the reduction of energy consumption and greenhouse gas emissions in the agricultural sector for our four different scenarios. Our results suggest that, although the impact of such policies is significant for the agricultural sector (through decreased production of energy and GHG intensive products), the impact of the resulting agricultural production patterns on Canadian energy consumption and GHG emissions is minimal due to the limited influence the agricultural sector has on total energy consumption and GHG emissions.

4.1 Introduction

Agricultural activities account for a significant amount of global greenhouse gas (GHG) emissions and, thus, are one of the main contributors to climate change. Indeed, in 2006, agriculture accounted for 13.5% of global emissions. This has led to considerable research interest towards exploring climate change mitigation options for the agricultural sector. There are two principal means of mitigation concerning agricultural activities. The first is through increasing the efficiency and/or negative environmental impact of agricultural production technologies. That is, where the same amount of agricultural good can be produced using less resources or 'cleaner' resources (fuels). The second means of mitigation is by changing the consumption patterns related to agricultural goods, whereby consumers demand products with lesser environmental impacts. This paper is concerned with the latter option, more specifically with agri-food consumption substitutions of meat and dairy products for plant-based foods and the resulting impact on energy usage and GHG emissions.

Canada's agricultural activities represent about 2% of total energy demand (Statistics Canada, 2011) and 8% of all Canadian GHG emissions (Environment Canada, 2012). Livestock production accounted for 59% of these emissions in 2010 without counting emissions tied to the production of animal feed. Therefore, a significant amount of Canada's GHG emissions are tied to the production of livestock products, more specifically to meat and dairy products. This production is determined by domestic demand, Canadian consumption of meat and dairy products, and by exports (foreign demand). For domestic consumption, there is a projected increase in annual per-capita meat consumption from 49.35 kg per person in 2010 to 52.77 kg in 2020 (Agriculture and Agri-food Canada, 2005). For dairy products[2], there is a projected decrease in Canadian consumption from 80.19 kg per capita in 2010 to 77.38 kg per capita in 2020. Additionally, a significant portion of livestock production is destined for exportation. Indeed, 50% of pork products and 21% of beef products were exported in 2010 (Statistics Canada, 2011).

We look at four different food policy scenarios where consumption of meat and dairy products is progressively substituted for plant-based products from 2007 to 2030. More

[2] The 'Selected Dairy' category in the Agriculture and Agri-food Canada (2005) publication includes fluid milk, cheese, cream and ice cream.

specifically, the consumption of beef, pork, poultry, eggs and dairy, is progressively substituted for grains and oilseeds, fruits, and vegetables. Indeed, our policy scenarios progressively restrict the consumption of certain agri-food products until the year 2030 when they are reduced by one third of their initial consumption level and substituted by food products that are not constrained by the scenario. The reduction rate is the same for the four scenarios; however, the scope of the food products varies

Throughout the literature, meat and dairy consumption reduction is presented as a viable option for GHG emission reduction; see for instance: Carlsson-Kanyama, Ekstrom and Shanahan (2002), Pimentel and Pimentel (2003), Eshel and Martin (2006), Carlsson-Kanayama and Gonzalez (2009), Environmental Working Group (2011), and Carlsson-Kanyama and Faist (2011). Their conclusions are based on a life cycle analysis (LCA) approach where environmental impacts of products are assessed at all stages of production. Indeed, these articles estimate the input/output relationships between agri-food products, their energy usage and the resulting GHG emissions. This paper considers an additional research step where these input/output relationships are implemented into a dynamic optimization energy model to determine the resulting impact as part of the whole Canadian energy system. Therefore, the static input-output data is implemented into such a model in order to obtain results for progressive consumption changes at the national level. We use the newly developed TIMES-Canada model (Vaillancourt et al, 2013), which is a dynamic optimization energy model used to perform economic analysis of the Canadian energy systems to obtain results for agricultural energy usage and GHG emissions for each of our policy scenarios and compare these results to our business-as-usual (BAU) scenario

The paper is organized as follows. In section 2, we present the TIMES approach and TIMES-Canada model. Section 3 covers the methodology for obtaining the input-output data for Canadian agri-food products and presents a comparison between our data and data from the literature. Section 4 describes the modelling of the Canadian agricultural sector. Section 5 explains our baseline scenario and our four policy scenarios. Finally, the results obtained by the model are discussed in section 6 and conclusions are drawn in section 7.

4.2 Methodology

4.2.1 TIMES approach

We use the TIMES-Canada model to assess the impact of different agri-food consumption patterns. A TIMES model (an abbreviation for The Integrated MARKAL-EFOM System) is a dynamic linear programming model for local, national or multi-regional energy systems analysis. It is part of the MARKAL family of models, which originated in the 1970s and is continuously developed within the ETSAP[3] program of the International Energy Agency. The model is used to make scenario-based projections for the energy sector of a particular economy by maximizing net social surplus. Additionally, it can be used for environmental policy assessments as GHG emissions are calculated for every process involved in attaining economic equilibrium.

The model can be delineated into three main types of components: technologies, commodities and commodity flows. First, technologies (or processes) are all the input-output relations implemented in the model, which transform commodities into other commodities. In this case, they are analogous to the input-output relationships provided by the LCA approach. For the agricultural sector, technologies were defined for eight production sub-sectors: grains and oilseeds, beef, dairy, poultry, eggs, pork, vegetables, and fruit. Each of these sub-sectors contains the different processes needed to transform primary materials and energy into agri-food products. For example, the beef sub-sector contains processes for transport, heating and lighting, and machinery needed to produce kilograms of beef. The modelling of these technologies will be covered in section 4.4. Second, commodities consist of energy carriers, energy services, materials, monetary flows, and emissions, which are either produced or consumed by the different technologies to satisfy the different demands. Last, commodity flows represent the links between the different processes and technologies. The commodity flow is a commodity that is linked to a specific process; it represents an input or output of that process. These three elements are organized into an RES (Reference Energy System), which is a network diagram illustrating the relationships between technologies, commodities and

[3]See: www.iea-etsap.org

commodity flows starting with energy supplies and ending with final demand. The RES for the agriculture sector is presented in section 4.1.

4.2.2 TIMES-Canada overview

Although an 11-region MARKAL model of the Canadian energy system has been developed at GERAD[4] in the past (see in particular Berger et al., 1992; Loulou et al., 1996; Kanudia and Loulou, 1999), a completely new database has been built to reflect the current situation on Canadian energy markets and to fit into the new TIMES modelling paradigm (Vaillancourt et al., 2013).

TIMES-Canada is now calibrated on to 2007 base year, using energy balances available at Statistics Canada (2007). It covers the energy system of the thirteen Canadian provinces and territories having their own reference energy system (RES), but linked together through energy, material as well as emission flows. The reference energy system of each province and territory is disaggregated as follows. In the energy supply side, two sectors are distinguished: electricity on the one hand, and supply of all other energy forms on the other. The former supply sector describes all central electricity and heat production, including combined heat and power and renewable potentials. The latter supply sector describes fossil fuel extraction, production and transformation processes, including petroleum refineries, as well as biomass potential. In the energy demand side, five sectors are considered: agriculture (AGR), commercial (COM), industrial (IND), residential (RSD) and transportation (TRA).

TIMES-Canada has already been used for sectoral analysis; see in particular Bahn et al. (2013).This paper is concerned with the agricultural sector. The standard representation of the agricultural sector in a TIMES model is simply the aggregation of the entire energy demanded by the sector, in MJ, for the different energy types. In order to allow for the analysis of the effects of substituting different consumption patterns with varying levels of meat and dairy products, the agricultural sector in TIMES-Canada was augmented to include production technologies for eight agricultural sub-sectors: grains and oilseeds, beef, dairy, poultry, eggs, pork, vegetables, and fruit.

[4] GERAD: Group for Research in Decision Analysis; HEC Montréal, Polytechnique Montréal, McGill University and Université du Québec à Montréal.

4.3 Data

The purpose of this section is to illustrate how the data used in the modelling of the Canadian agricultural sector was obtained. To implement the agricultural production technologies in TIMES-Canada three types of data were needed: energy use, GHG emissions and livestock feed requirements. First, energy use data was needed to obtain energy coefficients for agricultural production; these coefficients determine how much energy is required to produce a kilogram (kg) of product for the different TIMES-Canada technologies. Second, agricultural GHG emission data was needed to represent the amount of emissions for each technology. Finally, livestock feed requirement data was needed to determine the amount, in kg, of grains and oilseeds needed by our livestock producing technologies.

4.3.1 Energy input data

We estimated the energy input requirements for every agricultural production sector for each province by employing the 'Farm energy use survey' conducted by Statistics Canada (1997). It is the most recent agricultural energy usage database available with the level of detail necessary for modelling the input-output processes in TIMES-Canada. This data originates from a Canada wide telephone survey consisting of questions about farm energy usage by agricultural production sub-sector. The result is very detailed data providing energy usage ratios by province, fuel type, agricultural activity and agricultural sub-sector. As an illustration, table 2 shows the survey data for gasoline used by agricultural activities by sub-sector and activity type in Alberta. The survey provides similar tables for each province and each fuel type.

Table 2 - 1997 Statistics Canada energy use survey, gasoline usage in Alberta by sub-sector and activity type

		Gasoline usage within a subsector, by activity type				
Farm type	Gasoline usage by subsector	Trucks and auto	Heat and light	Other uses	Farm machinery	Non farm
Grains & oilseeds	27%	58%	0	0	20%	20%
Dairy	3%	63%	0	0	19%	18%
Cattle	43%	58%	0	0	20%	20%
Pork	3%	62%	0	0	19%	17%
Poultry and eggs	1%	59%	0	0	8%	27%
Fruit and vegetables	1%	46%	0	0	27%	27%
Greenhouse and nursery	1%	38%	0	0	21%	40%
Other	21%	57%	0	0	21%	19%
Total	100%					

4.3.2 Energy input coefficients

Energy input coefficients are needed to model agricultural input-output processes. The energy coefficients (MJ of energy by fuel type per kg of agricultural product produced) implemented in TIMES-Canada were estimated by disaggregating annual agricultural energy usage data from Statistics Canada (2011) for the years 2002 to 2009 by applying the energy usage ratios from the farm energy usage survey to the aggregate data. Subsequently, energy usage, by agricultural sub-sector and fuel type, were coupled with sub-sector production for each corresponding year, providing annual energy input coefficients for production for years 2002 to 2009. The agricultural technologies in TIMES-Canada were determined by applying a weighted average to the energy coefficients from 2002 to 2009, more weight was placed on recent data; the justification being that energy usage in recent years is more representative of energy use in future years. An example of our energy usage coefficients is given in Annexe A for the province of Alberta.

4.3.3 GHG emissions

Agricultural activities emit GHG emissions in addition to the ones tied to energy usage. Environment Canada categorizes these additional emissions into four groups: enteric fermentation, manure management, agricultural soils, and field burning of agricultural residues. We linked the data from Environment Canada (2012) to the agricultural production data in order to estimate emissions per kg of agricultural product. Table 3 shows the estimated amounts of GHG emissions, measured in kg of CO_2e emissions per kg of agricultural product:

Table 3 – GHG emissions (kg of CO_2e) per kg of agricultural product

	Agricultural Product							
Emission type	Beef	Dairy	Pork	Poultry	Eggs	G&O	Vegetables	Fruit
CH_4	13.95	0.41	1.26	0.11	-	-	-	-
N_2O	0.87	-	0.87	-	0.11	0.37	0.37	0.37

4.3.4 Feed Input

The amount of feed required by animal production must also be accounted for in order to obtain the full impact of a change in consumption patterns. We estimated feed requirements by calibrating data from a report by the United States Department of Agriculture (USDA, 2007) to national feed demand data from Statistics Canada (2011). Our results are shown in table 4.

Table 4– Feed input, kg of feed required to produce a kg of livestock product

	Agricultural Product				
	Beef	Dairy	Pork	Poultry	Eggs
Kg of feed	6.86	0.34	3.07	1.12	0.26

4.3.5 Overview

Table 5 provides an example of our input-output data. It shows the total inputs and outputs needed, or produced, by the beef production process, for Alberta, for each type of activity (energy usage is aggregated for all energy fuel types):

Table 5 – Beef production technology

Energy Input	MJ per kg of beef
Transport	8.16
Machinery	21.82
Heating and Light	3.48
Complementary	1.13
Feed Input	kg of feed per kg of beef
	6.86
GHG emissions	kg CO_2e per kg of beef
	14.8

4.3.6 Data results and comparison

Our coefficients for energy usage, measured in MJ per kg of food product, and GHG emissions, measured in kilograms of CO_2e emissions, estimated for TIMES-Canada, are presented below for the eight different types of agricultural products. Additionally, our coefficients are compared with coefficients found in the agricultural LCA literature.

First, table 6 compares our coefficients with the coefficients from Carlsson-Kanyama et al. (2002). Note however that their data is for the complete life-cycle as ours is confined to agricultural activities. Therefore, their energy usage coefficients are higher, as expected, but the ranking of most energy intensive animal product to least is identical: beef, pork, chicken, eggs and dairy.

Second, table 7 shows our coefficients for GHG emissions and compares it with the results from the Environmental Working Group (2011) and Carlsson-Kanyama and Gonzalez (2009) studies. Again, the latter research employs the complete life cycle as the research scope, thus providing higher GHG emission coefficients. On the other hand, the Environmental Working Group (2011) has an identical research scope to ours providing a more accurate benchmark.

Additionally, our data is specific to the Canadian context which can also explain differences with the data from Sweden employed in Carlsson-Kanyama, Ekstromb and Shanahan (2002), Carlsson-Kanyama and Gonzalez (2009), and the US data used by the Environmental Working Group (2011).

Table 6 – Energy usage by type of food produced, MJ per kg of product

	Agricultural Product							
Study	Beef	Pork	Chicken	Eggs	Dairy	G&O	Fruit	Vegetables
TIMES-Canada	33.74	29.27	9.96	4.98	4.66	2.6	1.92	0.64
Carlsson-Kanyama et al., 2002	48.74	35.6	29.6	18	5.45	5	3.5	5.4

Table 7 – GHG emissions by type of food product, kg CO_2e per kg of product

	Agricultural Product							
Study	Beef	Pork	Chicken	Eggs	Dairy	Vegetables	Fruit	G&O
TIMES-Canada	14.81	3.13	2.11	1.11	0.92	0.37	0.37	0.37
Environmental Working Group, 2011	15.23	4.62	2.33	2.12	1.062	0.28	-	0.23
Carlsson-Kanyama and Gonzalez, 2009	30	9.3	4.3	2.5	1	0.45	0.82	0.63

4.4 Modelling the agricultural sector in TIMES-Canada

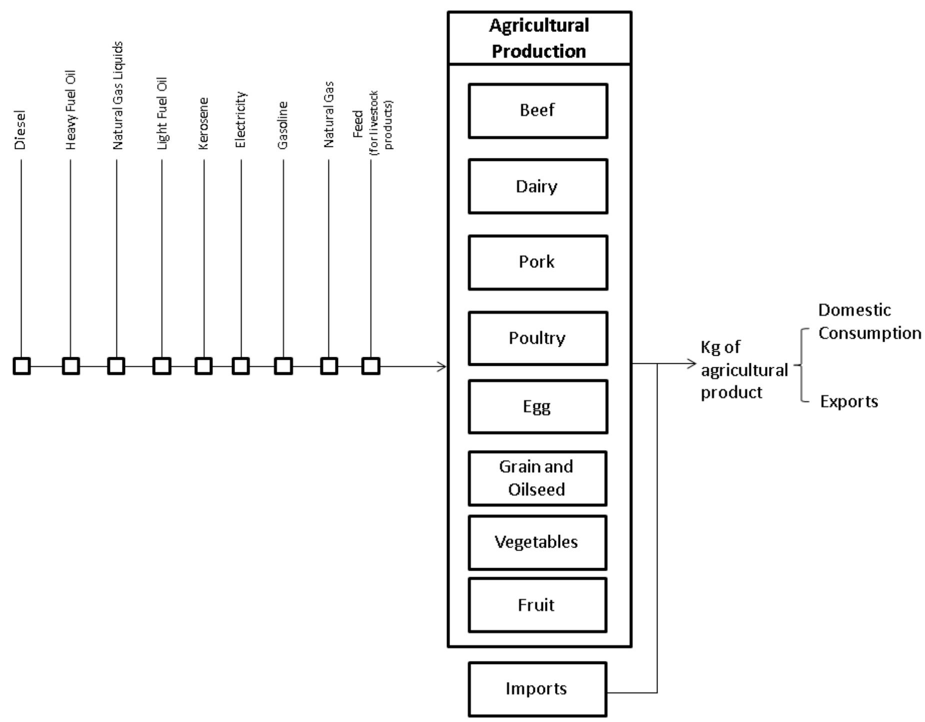
4.4.1 Reference Energy System

To allow for agri-food policy analysis, the energy demanded by the agricultural sector has to be a function of the demand for different agri-food products. In order to endogenize energy demand, the agricultural sector in TIMES-CANADA has been disaggregated into nine different sub-sectors: beef, dairy, poultry, egg, pork, grains and oilseeds, vegetables, fruit and other. The 'other' category of agricultural products is included as a fixed amount of energy demanded for all remaining agricultural products, which represented around 30% of total agricultural energy demand in 2009. In other words, about 70% of agricultural energy demanded is determined by the eight previously listed sub-sectors. Demand for these products is defined in terms of kg of agricultural product. This allows for agri-food consumption forecasts, which are expressed in terms of physical units, to be directly input into TIMES-Canada. Instead of having static amounts of energy required each year by the agricultural sector, energy demand is now tied to the demand for agricultural products measured in physical units (kg).

The reference energy system associated with the agricultural sector is given in figure 3. The fuel types used in the agricultural sector are shown on the left-hand side: heavy fuel oil, natural gas liquids (NGLs), light fuel oil, kerosene, electricity, gasoline, natural gas and diesel.

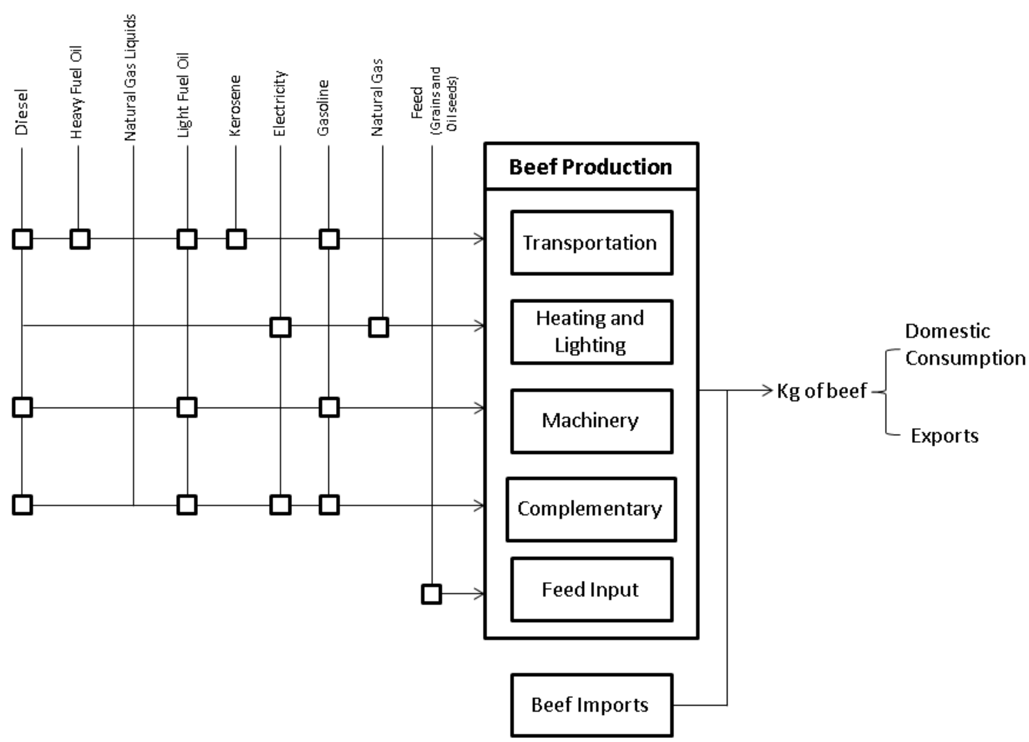
The eight agricultural production sub-sectors are present in the middle of the figure with their corresponding interdependencies; for example, production of grains and oilseeds (used as animal feed) is needed to produce meat and dairy products. Additionally, imports of poultry, vegetables and fruit are needed to satisfy domestic demand; they are the three categories characterized by negative net exports. On the right hand side, we have the total demand (domestic and foreign) constraint, which needs to be satisfied, and GHG emissions output generated by agricultural production technologies.

Figure 3 – RES for the Agriculture Sector



Next, figure 4 shows the RES for a specific production sector: beef. Energy inputs, shown on the left of the figure, are delineated for every production sub-sector's activities (transportation, heating and lighting, machinery, complementary, and feed input) and production sub-sector outputs are shown on the right. Agricultural transportation activities for beef production (which are included in agricultural energy use and separate from the transportation sector energy use as per Statistics Canada (CAEEDAC, 2000)) use diesel, heavy fuel oil, kerosene and gasoline for trucks, tractors, and other means of transportation. Agricultural heating and lighting activities for beef production use electricity and natural gas. Agricultural machinery activities for beef production use diesel, light fuel oil and gasoline for farm machinery. Finally, all other complementary activities for beef production, included in the 'complementary' category in the 'Farm energy usage survey' (Statistics Canada, 1997), use diesel, light fuel oil, electricity and gasoline. The feed requirement, determined by the model as a function of livestock production, is satisfied by using kg of product from the grains & oilseeds sub-sector. Therefore, demand for agri-food products (domestic demand + net exports) determines national agricultural energy usage through the transportation, heating and lighting, machinery and complementary activities of each sub-sector and for every province.

Figure 4 – RES for the beef sub-sector



4.4.2 TIMES-Canada agricultural technologies

The agricultural technologies implemented in the TIMES-Canada model were determined with input and output data presented in the Data section and integrated following the interdependencies illustrated by the agricultural Reference Energy System. They consist of all agricultural production input-output relationships between commodities used to satisfy projected agri-food demand. Furthermore, we have implemented production technologies for each agricultural sub-sector for every province. In other words, each province has unique production technologies which use differing input levels of different fuel types. For example, table 8 shows the different fuel inputs needed to produce 1 kg of grains and oilseeds for the province of Alberta.

Table 8 - Energy, MJ, used to produce 1 kg of grains and oilseeds by fuel type and activity type in Alberta

Alberta	Electricity	Kerosene	Light Fuel Oil	Gasoline	Natural Gas	Natural Gas Liquids	Diesel	Heavy Fuel Oil
GRAIN & OILSEED	**0.05**	**-**	**-**	**0.16**	**0.02**	**-**	**0.57**	**-**
Transport	-	-	-	0.09	-	-	0.03	-
Machinery	-	-	-	0.03	-	-	0.53	-
Heating and Light	0.02	-	-	-	0.01	-	-	-
Comlementary	0.01	-	-	-	-	-	-	-
Non-Farm	0.02	-	-	0.03	0.01	-	0.01	-

4.5 Scenario Characterization

This section presents the five scenarios used in our analysis: a baseline scenario (REF) and our four policy scenarios: a beef consumption reduction scenario (B); a beef, pork and poultry consumption reduction scenario (BPP); a beef, pork, poultry, eggs and dairy consumption reduction scenario (BPPED); and an international beef, pork, poultry, egg and dairy consumption reduction scenario (iBPPED). Each scenario consists of annual domestic consumption and net exports of agricultural products from 2007 to 2030 and the agricultural production constraints imposed on the model are defined as the sum of these two components; total production is determined by domestic consumption and net exports.

Our four policy scenarios are compared with the baseline scenario in order to evaluate the impact of such policies. These scenarios consist of a reduction of meat or dairy product consumption by one third (33%) by the year 2030. In other words, consumption is progressively and linearly reduced from 2009 to 2030, with the year 2030 representing 33% of the initial 2009 consumption level. The reduction amount is the same for the four following scenarios, only the scope of agricultural products for which consumption is reduced varies. Additionally, these consumption reductions are accompanied by substitutions for other agricultural products, which are detailed in each scenario description, the idea being that

Canadians will consume the same amount of food in terms of calories; it is only the composition of the diet that varies.

The choice of a one-third reduction policy is justified as follows. First, forecasted tendencies, such as the rise of vegetarianism, could not be used as a reference in order to determine the reduction rate; our goal is to look at the effect of less meat and dairy consumption in the whole population as oppose to no meat or dairy consumption in part of the population. Second, no actual meat or dairy reduction policies have been officially proposed in Canada, therefore, a ‘realistic’ reduction rate has not yet been determined. The 33% reduction level by 2030 was chosen because it is strong enough to provide appropriate insight into the effects of a meat reduction policy and low enough to be a realistic possibility. Table 9 compares our reduction rate with the ones employed by similar research.

Table 9 – Comparison of livestock product consumption reduction rates

Study	Reduction rate	Temporal span	Country	Product
Friel et al. (2009)	30%	2010 – 2030	UK, Brazil	Livestock Products
TIMES-Canada	33%	2010 – 2030	Canada	Livestock Products
Tukker et al.(2011)	40%	Static Analysis	Europe	Beef
Scarborough et al. (2012a)	50%	Static Analysis	UK	Livestock Products
Msangi and Rosegrant (2012)	50%	2010-2030	World	Livestock Products
Stehfest et al. (2009)	100%	2000-2050	World	Livestock products

4.5.1 Baseline scenario (REF)

The baseline scenario represents expected agri-food consumption patterns if no meat or dairy product consumption reducing policies are implemented. The baseline scenario is based on agriculture production and trade forecasts from Statistics Canada (2011). Data for 2009 to 2020 is directly taken from these projections and years 2021 to 2030 were estimated by using the average annual growth rate from years 2009 to 2020.

4.5.2 Beef consumption reduction scenario (B)

The consensus in the literature is that beef is the most polluting and energy intensive agricultural product; Environmental Working Group (2011), Carlsson-Kanayama and Gonzalez (2009), Eshel and Martin (2006), Pimentel and Pimentel (2003), Carlsson-Kanyama, Ekstrom and Shanahan (2002), and Carlsson-Kanyama and Faist (2011). Therefore, our first scenario consists of progressively and linearly reducing Canadian beef consumption until one third of consumption is substituted in 2030. Consumers are assumed to substitute their beef consumption with poultry and pork consumption, as these products are not constrained in this scenario. Substitution was assumed to be evenly split between poultry and pork. In other words, one kilogram of beef was substituted by half a kilogram of poultry and half a kilogram of pork.

4.5.3 Beef, pork and poultry consumption reduction scenario (BPP)

Beef, pork and poultry consumption is progressively reduced until 2030 where it represents two thirds of 2009 consumption. We assume the consumers substitute their agri-food consumption with an increased consumption of food grains, vegetables, fruit, dairy, and eggs. The distribution of meat substitution amongst these agri-food categories was taken from Pimentel (2003) and is presented in table 10.

Table 10 – Caloric substitution of meat consumption by different agri-food categories

	Agricultural Product				
	Food Grains	Vegetables	Fruit	Dairy	Eggs
% Increase for a lacto-ovo-vegetarian diet	33%	20%	2.75%	20%	32.75%

4.5.4 Beef, pork, poultry, eggs and dairy consumption reduction scenario (BPPED)

Beef, pork, poultry, egg and dairy consumption is progressively reduced until 2030 where it represents two thirds of 2009 consumption. Consumers are assumed to substitute the decrease in egg and dairy consumption by increasing their grain and vegetable consumption. Caloric substitution is assumed to be 90% from grains and oilseeds and 10% from vegetables (Pimentel, 2003).

4.5.5 International beef, pork, poultry, egg and dairy consumption reduction scenario (iBPPED)

A significant portion of Canadian meat and dairy products is tied to foreign demand. Our international beef, pork, poultry, egg and dairy consumption reduction scenario extends the BPPED scenario consumption reductions to all countries importing meat and dairy from

Canada keeping the same food substitution assumptions. This enables the delineation of the environmental impact of meat and dairy product exports by contrasting results with our domestic consumption reduction scenario. Table 11 shows the percentage of meat and dairy production exported in 2009 (Statistics Canada, 2011).

Table 11 – Proportion of production which was exported in 2009

	Agricultural Product				
	Beef	Pork	Poultry	Egg	Dairy
Proportion of exports to total production	21%	50%	-5% (imported)	1%	3%

4.5.6 *Production constraints for the policy scenarios*

These four policy scenarios (B, BPP, BPPED, iBPPED) impose constraints on the production of agricultural products, which are shown in figures 5 and 6 for the year 2030. Figure 5 shows the agricultural production, in megatonnes (MT) imposed by the different policy scenarios for the following sub-sectors (in order of production level in the reference scenario): dairy, vegetables, pork, beef, poultry, fruit and eggs. It allows for a comparison with our reference scenario. The restrictions on the consumption of certain food products in each scenario and the resulting consumption substitutions discussed in the previous sub-sections are succinctly summarized. Figure 6 shows the production levels of grains and oilseeds for the year 2030 for our different policy scenarios. It is interesting to see the dual effect meat and dairy consumption policies have on the production of grains and oilseeds. Indeed, on the one hand, reducing meat and dairy consumption reduces feed production and has a diminishing effect on grain and oilseed production. On the other hand, part of the foregone meat and dairy consumption will be substituted for grain and oilseed consumption. For example, the BPP and BPPED scenarios show an increased grain production in 2030 whereas the iBPPED shows a decreased production when compared to the reference scenario.

Figure 5 – Agricultural production constraints imposed by our different scenarios in the year 2030

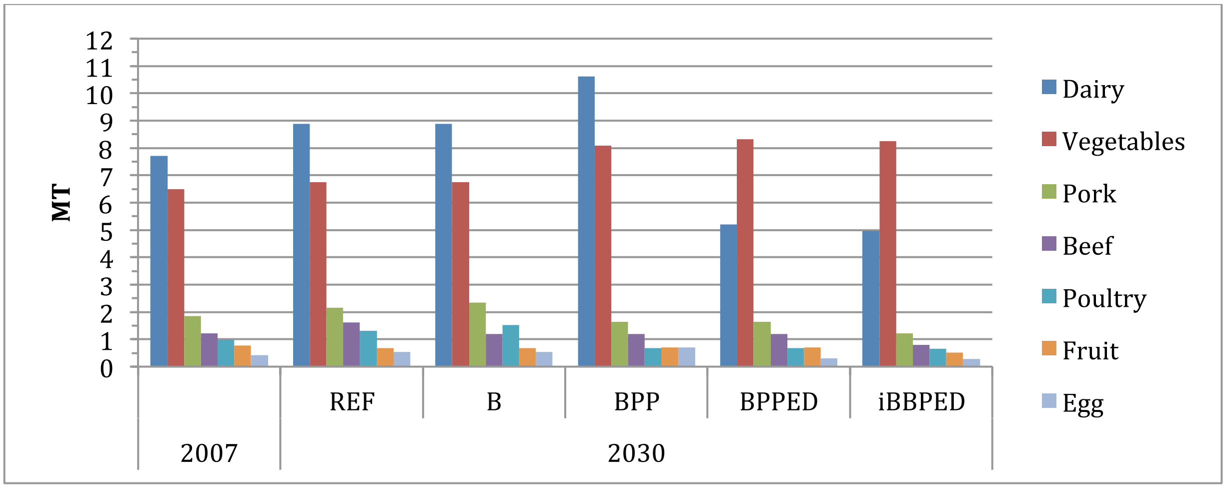
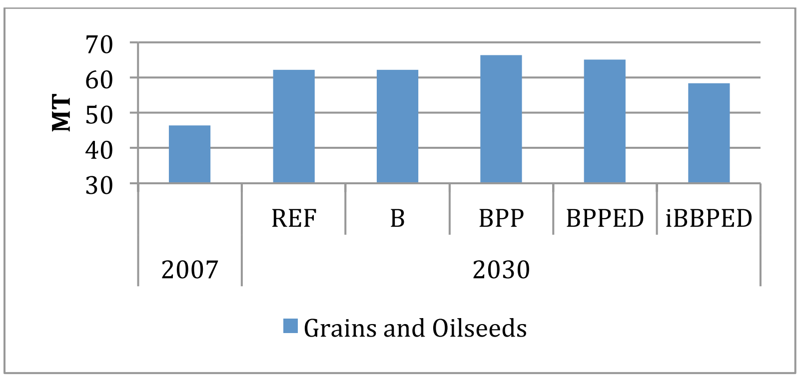


Figure 6 – Grains and oilseeds production constraints imposed by our different scenarios in the year 2030



4.6 Results

This section shows the results for our five different scenarios introduced in the previous section (REF, B, BPP, BPPED and iBPPED). Times-Canada was used to obtain results on energy production and consumption, and GHG emissions for each scenario. The results are presented at the sectoral level; the impact of consumption substitution on the agricultural sector, and at the national level; the impact of consumption substitution on aggregate Canadian energy production, energy consumption and GHG emissions. The comparison of results at these two different levels allows for a more complete perspective on the potential impact of a meat and dairy consumption reduction policy; significant impact relative to agricultural sector energy consumption and production, and GHG emissions might be negligible when compared to the aggregated activity from all Canadian energy sectors. It is important to note that our analysis of energy and emissions related effects are performed for the agricultural sector only. In other words, the impact that these consumption reduction policies would have in the other sectors (residential, commercial, industrial and transportation) is not taken into account. Therefore, our results for the impact at the national level should not be seen as the impact of all sectors of such meat and dairy consumption reduction policies, but rather as the effect of such policies via the agricultural sector. Furthermore, the LCA literature suggests that the agricultural sector is responsible for the majority of the impact on energy consumption and GHG emissions, see, for instance, the coefficients estimated in Carlsson-Kanyama, Ekstromb and Shanahan (2002), Carlsson-Kanyama and Gonzalez (2009), and the Environmental Working Group (2011); which are summarized in tables 6 and 7 (section 3.6).

4.6.1 Primary energy supply

First, figure 7 presents first the evolution of primary energy supply by energy sources in the baseline scenario.

Figure 7 - Primary energy supply by fuel in the baseline scenario, 2007-2030

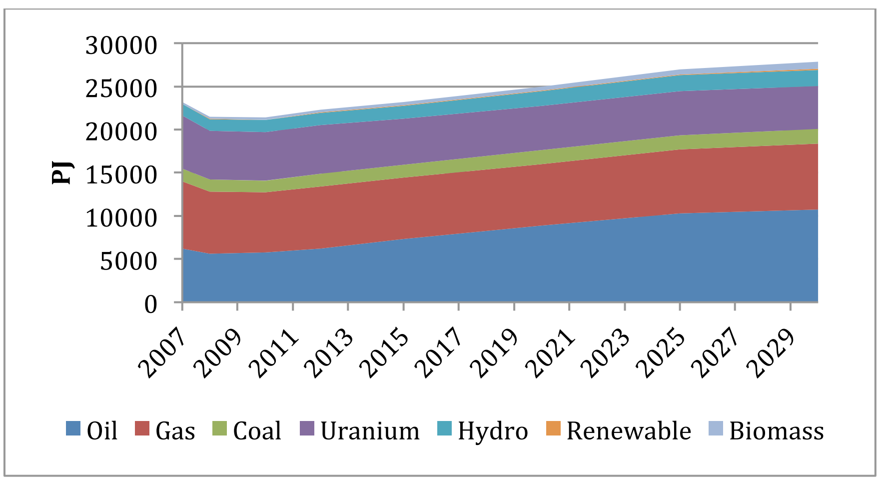


Figure 7 indicates that the share of fossil fuels in the energy supply mix remains approximately constant (around 70%) over time, but with a decrease in coal and natural gas supply compensated by an increase in oil supply (increase absorbed by foreign markets). One can note also that the share of renewable (including hydro) and biomass production will increase progressively after 2015. Compared to our baseline scenario, the energy supply mix in 2030 remains relatively unchanged for our four policy scenarios: B, BPP, BPPED and iBPPED.

4.6.2 *Final energy consumption*

Figure 8 reports next on the breakdown of final energy consumption by fuel in the baseline. Between 2007 and 2030, final energy consumption increases by around 27%, following exogenous assumptions on economics and population growth, in particular. The share of oil in the fuel mix is reduced over time principally in favour of biomass. These trends can be explained on the one hand by the assumed increases of oil prices on international markets, and, on the other hand, by the large variety of options available in Canada for biomass production (including biofuels for transportation).

Figure 8 - Final energy consumption by fuel in the baseline scenario, 2007-2030

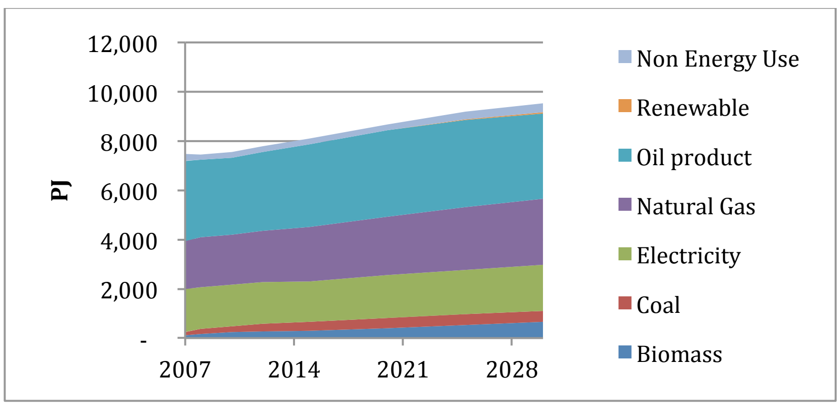
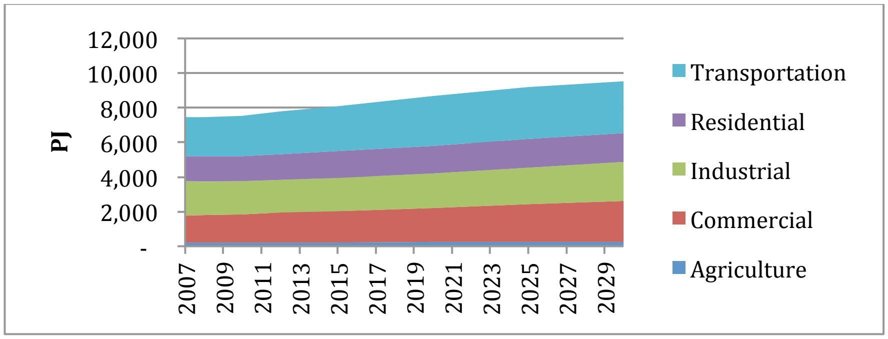


Figure 9 reports on the breakdown of final energy consumption by end-use sector. We can see the relatively weak share of total energy consumption attributed to the agricultural sector. Indeed, the agricultural sector represents between 2.7% and 3% of total energy consumption between 2007 and 2030. Therefore, any agricultural policy will have limited influence on total Canadian energy consumption. Thus, this explains why our four meat and dairy reduction policy scenarios have relatively no impact on total energy consumption.

Figure 9 - Final energy consumption by end-use sector in the baseline scenario, 2007-2030



Now, if we look more closely at the agricultural sector, figure 10 shows, the final energy consumption for three different fuel types: natural gas and NGLs, electricity and heat, and oil products, in the agricultural sector for our baseline scenario. Total fuel consumption increases by 25% from the year 2007 to 2030. This increase is mainly explained by the expected increase in Canadian population leading to an increased demand for agricultural products. The share of each fuel type remains relatively similar. The share of oil decreases by around 10%, from 72% in 2007 to 62% in 2030, effectively being progressively replaced by the two other fuel sources.

Figure 10 - Final energy consumption by fuel in the agricultural sector, for the baseline scenario, 2007-2030

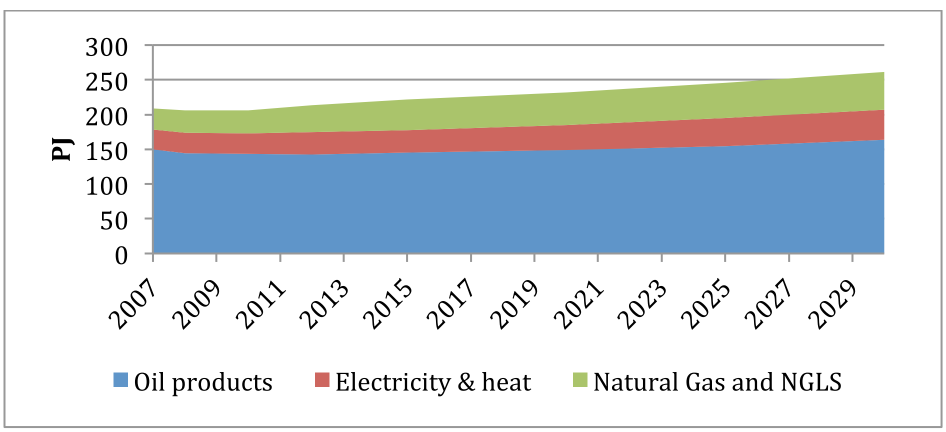
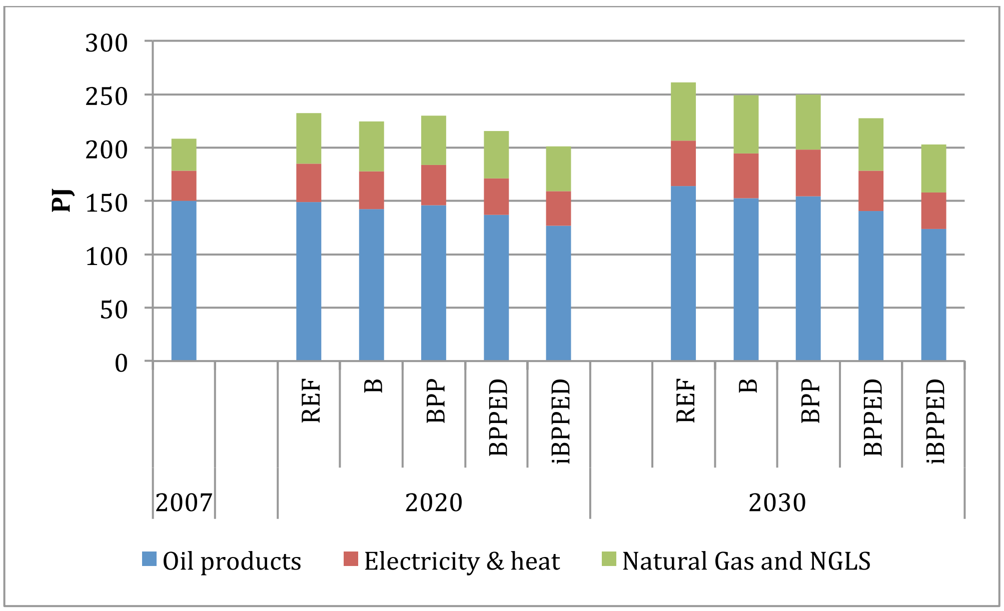


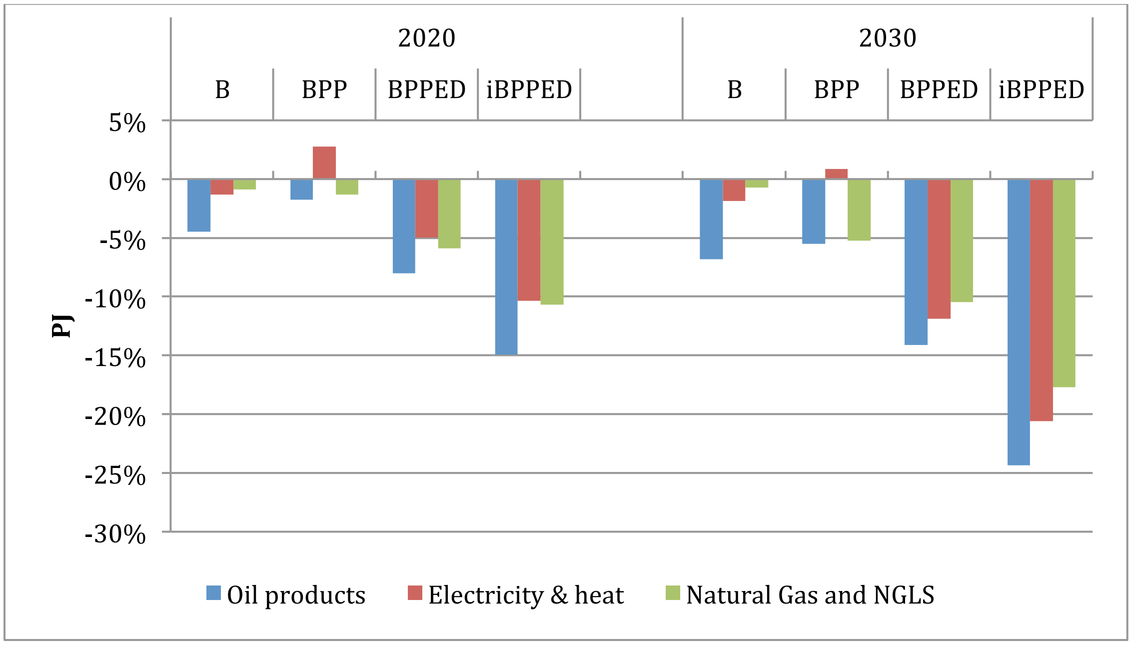
Figure 11 shows the final energy consumption in the agricultural sector for our five different scenarios. We can see that adding consumption restrictions does not necessarily equate to lower energy consumption, as the beef, pork and poultry (BPP) scenario consumes more energy than the beef reduction scenario. This is explained by the fact that the pork and poultry consumption in the BPP scenario is substituted by dairy and egg consumption. This substitution leads to the higher aggregate energy consumption. As expected the most constraining meat and dairy consumption reduction policy scenarios are the ones with the lowest aggregate energy consumption. Indeed, for the year 2030, the beef, pork, poultry, egg and dairy (BPPED) reduction scenario and the international BPPED (iBPPED) scenario consumed 15% and 29% less energy, respectively, when compared to our baseline scenario.

Figure 11 - Final energy consumption by fuel in the agricultural sector, for the different scenarios, 2007-2030



The relative change from the baseline scenario for each type of fuel is shown in figure 12 for the years 2020 and 2030. Indeed, we can now see that the additional energy consumption of the beef, pork and poultry reduction scenario (BPP), when compared to the beef reduction scenario (B), is due to an increase in the use of electricity and heat which can be traced most notably to the increased consumption of dairy (which is very electricity and heat intensive). Other than this increase, every other fuel consumption is decreased in our four policy scenarios. It is interesting to note that a 33% reduction of beef consumption (B) leads to a 7% decrease in agricultural consumption of oil products.

Figure 12 - Percentage difference in energy consumption for B, BBP, BBPPED and iBPPED compared to REF, 2007-2030



4.6.3 GHG emissions

The results for total Canadian GHG emissions are displayed in figure 13 for our baseline scenario and our four policy scenarios. We can see that our three first scenarios (B, BPP and BPPED) have little effect on total Canadian GHG emissions; they average for a decrease of around 13 megatonnes of CO_2 equivalent (Mt CO_2e) in the year 2030. The international beef, pork, poultry, egg and dairy reduction scenario has a stronger effect on total Canadian GHG emissions: around 27 Mt CO_2e. This means that around 14 Mt CO_2e can be tied to foreign demand for meat and dairy agricultural products, more than what is tied to purely domestic consumption (13 Mt CO_2e).

Figure 14 shows the same results but only for the agricultural sector. It is interesting to note that the beef reduction policy (B) is preferred, in terms of minimizing GHG emissions, to the more constraining beef, pork and poultry (BPP) reduction policy. This result stems from the caloric substitution of pork and poultry for other agricultural products. The amount, in terms of kg, of other agricultural products (dairy, egg, grains and oilseeds, vegetables, and fruit) needed to replace the caloric loss is such that the GHG emissions for the BPP scenario exceed emissions from the B scenario even though the products being substituted for have lower GHG emission coefficients (relative to kg of product) than the pork and poultry GHG emission coefficients (see table 7; section 3.6). We also see that the international meat and dairy consumption reduction policy scenario (iBPPED) is the only scenario in which the positive GHG emissions trend is reversed for the agricultural sector; GHG emissions are decreasing in time.

Figure 13 - Canadian emissions for the different scenarios, 2007-2030

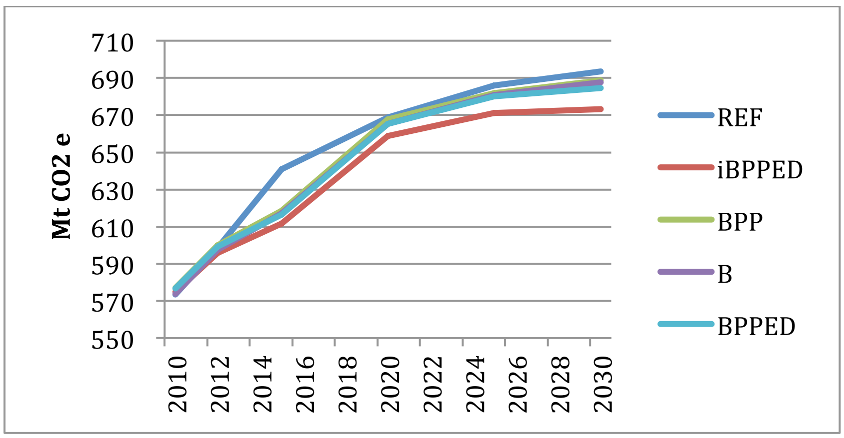
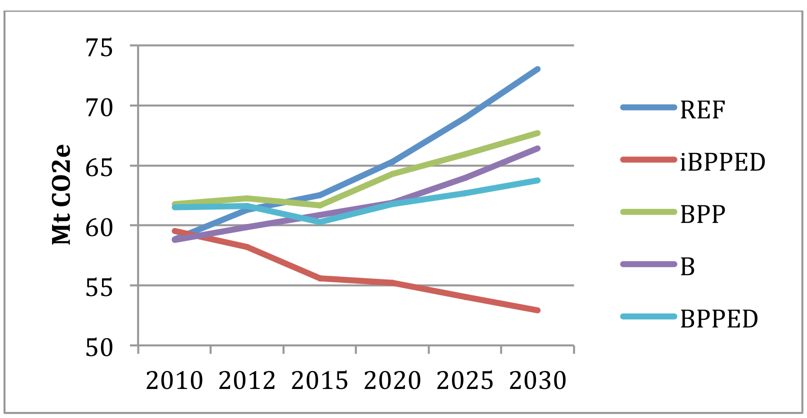


Figure 14 - GHG emissions from the agricultural sector for the different scenarios, 2007-2030



4.7 Conclusion

In this paper, we use the newly developed TIMES-Canada model to analyze the impacts of meat and dairy consumption reduction policies on Canadian energy consumption and GHG emissions. We contrasted four different consumption reduction policies to a baseline scenario. The scenarios employed in the analysis span until 2030 and differ in the scope of their consumption restrictions, the magnitude of the restriction is the same for all policy scenarios: a one third reduction by 2030. Therefore, we have scenarios for a beef reduction policy (B), a beef, pork and poultry reduction policy (BPP), a beef, pork, poultry, egg and dairy reduction policy (BPPED), and, finally, an international beef, pork, poultry, egg and dairy reduction policy (iBPPED) where the same constraint is imposed on foreign demand for said products.

Our analysis shows that although the effect of our consumption reduction policy scenarios is significant within the agricultural sector, the impact is very limited on total Canadian energy consumption and GHG emissions (via the agricultural sector). Therefore, although energy usage and GHG emissions tied to certain agri-food products vary significantly, a long-term reduction (by one third) of consumption of meat and dairy products (more energy intensive and higher relative GHG emissions) for grains and oilseeds, vegetables, and fruit (less energy intensive and GHG emitting), the aggregate effect of such consumption changes is not significant; our most constraining scenario (iBPPED) results in a decrease of around 4% of Canadian GHG emissions in 2030 and 2% of Canadian energy consumption. Considering these results, the justification of implementing such policies would be difficult, especially when considering the importance of the livestock sector to the Canadian economy and the fact that the only policy scenario with a noticeable impact was one where exports of livestock products were reduced by one third by 2030 (iBPPED).

It is important to restate that our analysis is limited to the agricultural sector; we look at the impact such policies have on energy consumption and GHG emissions in the agricultural sector. As such, the effects on total Canadian energy consumption and GHG emissions stem from the agricultural sector only. Meaning, the effects of such meat and dairy consumption reduction policies on the energy consumption and GHG emissions of other sectors, such as the transport and residential sectors, is not taken into account. Indeed, the total impact may be larger if looking at the effect on all sectors. However, the extension of our current agri-food framework within TIMES-Canada to its other sectors is an interesting research avenue. That is, the extension of our model to include effects of dietary changes on the transportation sector (food transportation), residential sector (food preparation), industrial sector (food processing) and commercial sector (food stocking) could provide interesting results.

Additionally, the health effects of reduced meat and dairy consumption are beyond the scope of our analysis. There is considerable research pointing to the health benefits of substituting meat and dairy consumption for plant-based foods, see for instance (Campbell and Campbell, 2006). For countries with public healthcare systems such as Canada, such consumption reduction policies could provide additional benefits in the form of less healthcare expenses and, when coupled with the effects on energy consumption and GHG emissions, might justify the implementation of meat and dairy consumption reduction policies in Canada.

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Annexe A –Energy usage coefficients for Alberta, MJ per kg of agricultural product

Alberta	Electricity	Kerosene	Light Fuel Oil	Gasoline	Natural Gas	Natural Gas Liquids	Diesel	Heavy Fuel Oil
GRAIN & OILSEED	**0.05**	**-**	**-**	**0.16**	**0.02**	**-**	**0.57**	**-**
Transport	-	-	-	0.09	-	-	0.03	-
Machinery	-	-	-	0.03	-	-	0.53	-
Heating and Light	0.02	-	-	-	0.01	-	-	-
Comlementary	0.01	-	-	-	-	-	-	-
Non-Farm	0.02	-	-	0.03	0.01	-	0.01	-
DAIRY	**0.65**	**-**	**0.01**	**0.51**	**0.32**	**0.01**	**1.37**	**-**
Transport	-	-	-	0.32	-	-	0.05	-
Machinery	-	-	-	0.10	-	-	1.29	-
Heating and Light	0.37	-	-	-	0.18	-	-	-
Comlementary	0.10	-	-	-	0.02	-	0.03	-
Non-Farm	0.17	-	-	0.09	0.11	-	-	-
CATTLE	**5.55**	**0.01**	**0.08**	**9.72**	**2.92**	**0.21**	**22.76**	**0.02**
Transport	-	0.01	0.01	5.64	-	-	2.50	-
Machinery	-	-	0.07	1.94	-	-	19.80	0.02
Heating and Light	2.44	-	-	-	0.96	0.07	-	-
Comlementary	0.78	-	-	0.19	0.15	0.01	-	-
Non-Farm	2.33	-	-	1.94	1.81	0.13	0.46	-
PORK	**2.52**	**-**	**0.01**	**1.53**	**1.62**	**0.03**	**3.39**	**-**
Transport	-	-	-	0.95	-	-	0.17	-
Machinery	-	-	0.01	0.29	-	-	3.19	-
Heating and Light	1.63	-	-	-	0.97	0.02	-	-
Comlementary	0.10	-	-	0.03	0.13	-	0.03	-
Non-Farm	0.78	-	-	0.26	0.52	0.01	-	-
POULTRY	**2.98**	**-**	**0.01**	**1.02**	**4.18**	**0.03**	**2.58**	**-**
Transport	-	-	-	0.60	-	-	0.90	-
Machinery	-	-	0.01	0.08	-	-	1.50	-
Heating and Light	2.23	-	-	-	3.43	0.02	-	-
Comlementary	0.27	-	-	0.06	0.04	-	0.18	-
Non-Farm	0.48	-	-	0.28	0.71	-	-	-
EGGS	**1.49**	**-**	**-**	**0.51**	**2.09**	**0.01**	**1.29**	**-**
Transport	-	-	-	0.30	-	-	0.45	-
Machinery	-	-	-	0.04	-	-	0.75	-
Heating and Light	1.12	-	-	-	1.72	0.01	-	-
Comlementary	0.13	-	-	0.03	0.02	-	0.09	-
Non-Farm	0.24	-	-	0.14	0.36	-	-	-
FRUIT	**0.33**	**-**	**-**	**0.22**	**0.11**	**-**	**0.52**	**-**
Transport	-	-	-	0.10	-	-	-	-
Machinery	-	-	-	0.06	-	-	0.44	-
Heating and Light	0.13	-	-	-	0.02	-	-	-
Comlementary	0.08	-	-	-	0.01	-	0.08	-
Non-Farm	0.12	-	-	0.06	0.09	-	-	-
VEG	**0.11**	**-**	**-**	**0.07**	**0.04**	**-**	**0.17**	**-**
Transport	-	-	-	0.03	-	-	-	-
Machinery	-	-	-	0.02	-	-	0.15	-
Heating and Light	0.04	-	-	-	0.01	-	-	-
Comlementary	0.03	-	-	-	-	-	0.03	-
Non-Farm	0.04	-	-	0.02	0.03	-	-	-

Chapter 5

Conclusion

The results for our different food policy scenarios show that Canadian consumption of meat and dairy products has a significant effect on the agricultural sector's energy usage and greenhouse gas emissions. However, the viability of such a policy option is debatable. Two main issues hinder the potential effectiveness of Canadian meat and dairy consumption reduction policies. First, the policy with the highest climate change mitigation potential (iBPPED) is dependent on reducing foreign demand for Canadian meat and dairy products. This decrease in demand cannot be as easily achieved as in the case of reducing domestic demand. Additionally, if this foreign demand reduction were attained, through some sort of trade tariff, the economic repercussions for Canada's agricultural sector would be substantial. Second, the influence of Canada's agricultural sector on national energy usage and GHG emissions is weaker relative to the other energy sectors: transport, commercial, residential and industrial. Therefore, climate change mitigation policies concerning these energy sectors may prove to be more cost effective when looking at national level effects.

However, further research on meat and dairy reduction policies may increase their perceived viability. First, assessing the impact of such policies on Canada's other energy sectors may show that the combined intersectoral effect substantially decreases national energy usage and GHG emissions. For example, effects of dietary changes on the transportation sector (food transportation), residential sector (food preparation), industrial sector (food processing) and commercial sector (food stocking) may result in considerable aggregate environmental impacts. Second, the potential health benefits of decreasing meat and dairy consumption may prove to be a substantial secondary effect of such a policy. Indeed, the monetary gains related to a healthier population in a country with a public health system such as Canada may justify the implementation of a meat and dairy consumption reduction policy, especially when combined with the positive environmental results we have shown.