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Assessing the long-term mitigation
potential of alternative agri-food
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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 model of the entire Canadian energy system (TIMES-Canada) to assess the climate change mitigation potential of different agri-food consumption patterns in Canada. For this, our model has been extended by disaggregating the agricultural demand sector into individual agri-food demands to allow for a more in-depth analysis. Besides a business-as-usual (baseline) scenario, we have constructed four different agri-food scenarios to assess the viability of reducing Canadian meat and dairy consumption in order to diminish Canada's agricultural sector energy consumption and greenhouse gas (GHG) emissions. Our policy scenarios progressively restrict the consumption of different meat and dairy agricultural products until the year 2030. Our results suggest that the implementation of a meat and dairy consumption reduction policy would lead to a 10% to 40% reduction in agricultural GHG emissions, depending on the severity of the scenario. This translates to a 1% to 3% decrease in total Canadian GHG emissions by the year 2030. Besides these environmental benefits, health benefits associated with a reduction in meat and dairy consumption (as inferred from other studies) are presented as an additional source of motivation for implementing such a policy in Canada.

Key Words: Food consumption patterns, policy analysis, consumer behaviour, climate change, energy sector modeling.

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1 Introduction

Climate change has emerged as a contemporary critical 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 maximize the reduction of greenhouse gas (GHG) emissions.

Agriculture accounted for 14% of global emissions in 2010, which is slightly less than the transportation sector's contribution of 15% (World Bank, 2014). Furthermore, the majority of agricultural emissions are tied to livestock related activities (Garnett, 2009). Therefore, the reduction of meat and dairy consumption has been put forward as a viable mitigation option and has been recommended by the IPCC. However, global meat and dairy 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 over the same time span (Dairy Co, 2013).

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 totalled 56 million tonnes of CO₂ equivalent (CO₂-eq) 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 Canadian consumption from 80.19 kg per capita in 2010 to 77.38 kg per capita in 2020.

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 pertinent 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 consumption on Canadian agricultural energy usage and GHG emissions?

Additionally, there are individual health benefits to reducing consumption of meat and dairy products, see for instance Friel et al. (2009), Stehfest et al. (2009), Msangi and Rosegrant (2011), Tukker et al. (2011), and Scarborough et al. (2012). Two interesting elements arise from this link between meat and dairy demand, and health. First, consumption pattern modifications can be motivated by the individuals themselves if they are concerned with optimizing their health benefits by their agrifood consumption choices. Therefore, policymakers can utilize this link in order to bring forth collective environmental benefits such as energy usage and GHG emission reduction. Indeed, the difficulty of motivating collective action can be bypassed by motivating individuals through their health concerns. This also provides a lower-cost option for altering consumption patterns as a simple information based persuasion policy aimed at aligning consumption patterns with health optimizing behaviour might prove sufficient for attaining the desired consumption reduction rate.² Second, since Canada employs a public health-care system, the health of individuals is directly correlated with public health care expenditures. Therefore, there might be a significant monetary benefit to promoting reduced meat and dairy consumption to go along with the environmental benefits. Therefore, both these elements, individual motivation and the public health-care system, help justify the implementation of such a policy.

Throughout the literature, meat and dairy consumption reduction is presented as a viable option for GHG emission reduction; see for instance: Carlsson-Kanyama, Ekström and Shanahan (2002), Pimentel and Pimentel (2003), Eshel and Martin (2006), Carlsson-Kanayama and Gonzalez (2009), Carlsson-Kanyama and Faist (2011), and Environmental Working Group (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. Once these input-output relationships (i.e. MJ of energy or CO₂-eq emissions

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

² The effectiveness of such information provision based strategies has recently been questioned. For example, a recent literature review by the Food Climate Research Network (FCRN, 2015) has concluded that: "approaches aimed at getting individuals to change voluntarily have limited impacts".

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 article 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.

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 policy 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 newly developed TIMES-Canada model (Vaillancourt et al., 2014), a dynamic optimization energy model used to perform economic analysis of the Canadian energy systems. The results from these scenarios are contrasted to illustrate the potential impact of meat and dairy product consumption reduction policies.

The paper is organized as follows. In Section 2, we present the TIMES approach. 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.

2 Methodology

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 optimization 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 ETSAP³ 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. Second, commodities consist of energy carriers, energy services, materials, 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; 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 commodity flows starting with energy supplies and ending with final demand. The RES for the agriculture sector is presented in Section 4.1.

³ Energy Technology Systems Analysis Program; see: www.iea-etsap.org.

2.2 TIMES-Canada overview

Although an 11-region MARKAL model of the Canadian energy system has been developed at GERAD⁴ 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., 2014).

TIMES-Canada is now calibrated to a 2007 base year, using energy balances available at Statistics Canada (2007). It covers the energy system of the 13 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) which studies the transportation sector. 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.

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 create 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 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.

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 in 1997. It is the most recent agricultural energy usage data available with the level of detail necessary for modelling the input-output processes in TIMES-Canada. The 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 example, Table 1 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.

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 the TIMES-Canada model were estimated by disaggregating agricultural energy usage data from Statistics Canada (2011) for the

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

Table 1: 1997 Statistics Canada energy use survey, gasoline usage in Alberta by sub-sector and activity type

Farm type	Gasoline usage distribution by subsector	Gasoline usage distribution within a subsector, by activity type (numbers may not sum to total due to rounding)				
		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%
Hog	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%					

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 energy input coefficients for production for years 2002 to 2009. The agricultural technologies in the TIMES-Canada model 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 Appendix A for the province of Alberta.

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 2 shows the estimated amounts of GHG emissions, measured in kg of CO₂-eq emissions per kg of agricultural product:

Table 2: GHG emissions (kg of CO₂-eq) per kg of agricultural product

Emission type	Agricultural Product							
	Beef	Milk	Pork	Poultry	Eggs	Grains and Oilseeds (G&O)	Veges	Fruit
CH ₄	13.95	0.41	1.26	0.11	–	–	–	–
N ₂ O	0.87	–	0.87	–	0.11	0.37	0.37	0.37

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 (2007) to national feed demand data from Statistics Canada (2011). Our results are shown in Table 3.

Table 3: Feed input, kg of feed required to produce a kg of livestock product

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

3.5 Overview

Table 4 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 4: 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 ₂ -eq per kg of beef 14.8

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 CO₂-eq emissions, estimated for the TIMES-Canada model, 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 5 compares our coefficients with the coefficients from Carlsson-Kanyama et al. (2002). However, their data is for the complete life-cycle as ours is confined to agricultural activities. Therefore, their energy usage coefficients are higher,⁵ as expected, but the ranking of most energy-intensive animal product to least is identical: beef, pork, chicken, eggs and dairy.

Second, Table 6 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 leading to 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, Ekström and Shanahan (2002), Carlsson-Kanyama and Gonzalez (2009), and the US data used by the Environmental Working Group (2011). Indeed, national differences in farm size, climate, energy supply, etc., affect agricultural energy usage and emissions data for each country.

⁵ Data from a lifecycle study with larger boundaries is expected to lead to increased energy and GHG emission coefficients as more processes are included when aggregating total energy usage and emissions (such as food processing, transport storage, etc.).

Table 5: Energy usage by type of food produced, MJ per kg of product

Study	Agricultural Product							
	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 6: GHG emissions by type of food product, kg CO₂-eq per kg of product

Study	Agricultural Product							
	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 Modelling the agricultural sector in TIMES-Canada

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 kilograms (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).

Using TIMES-Canada for food policy analysis allows for several interesting analytical possibilities which do not appear in the current literature. First, the level of detail in the TIMES-Canada model allows for fuel specific results (i.e.: the different levels of electricity consumption for our different food policy scenarios). Indeed, different food consumption patterns lead to different fuel mixes. For example, substituting meat consumption by dairy consumption tends to increase total electricity demand, as dairy production is an electricity intensive activity (see Figure 8 for fuel specific results). Second, the interdependency between grains and oilseeds (G&O) and livestock is fully captured by the model, which allows for a clearer picture of the uncertainty related to energy and environmental impacts of grain production. This uncertainty arises in the following manner: on the one hand, reduced meat consumption leads to increased grain production in order to substitute the fall in caloric intake of the imposed diet. On the other hand, less livestock production means less grains and oilseeds need to be produced in order to feed livestock. Third, since TIMES-Canada is a model of the complete Canadian energy system, and it is optimized by using the total cost of the entire energy system as the objective function, we obtain results for the different total costs of our different food consumption scenarios.

The reference energy system associated with the agricultural sector is given in Figure 1. 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. 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 created by agricultural production technologies.

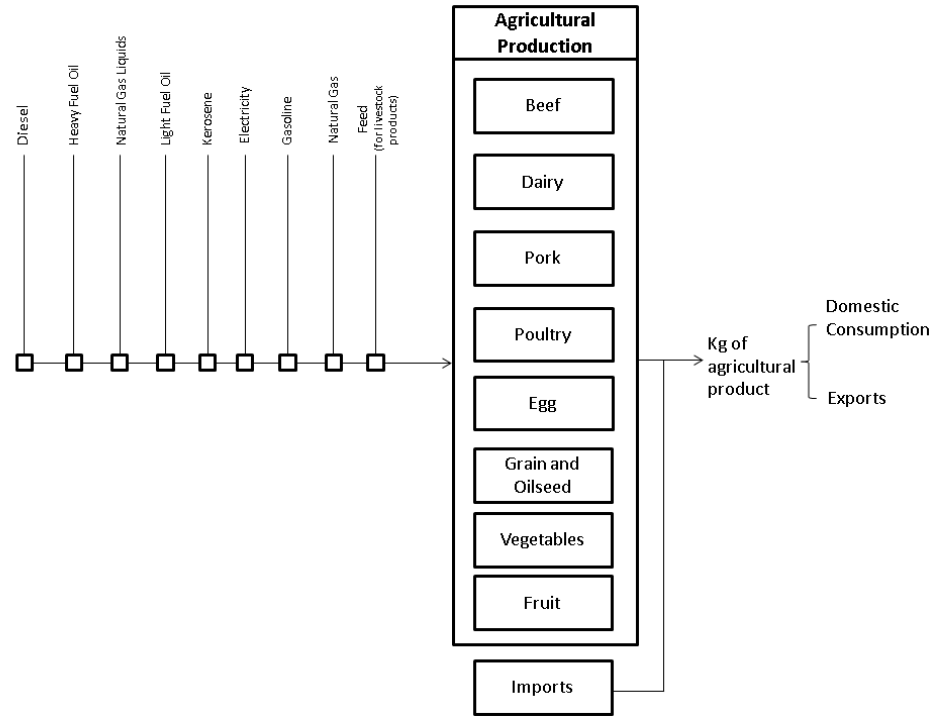


Figure 1: RES for the agriculture sector

Next, as an illustration, Figure 2 shows the RES for a specific production sector: beef. Energy inputs, shown on the left of the figure, are delineated for every production sector sub-activity (transportation, heating and lighting, machinery, complementary, and feed input) and production 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 (the sum of domestic demand and net exports) determines national agricultural energy usage through the transportation, heating and lighting, machinery and complementary activities of each sub-sector for every province.

4.2 TIMES-Canada agricultural technologies

The agricultural technologies implemented in the TIMES-Canada model were determined with the 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 each and every province. In other words, each province has unique production technologies which use differing input levels of different fuel types.

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

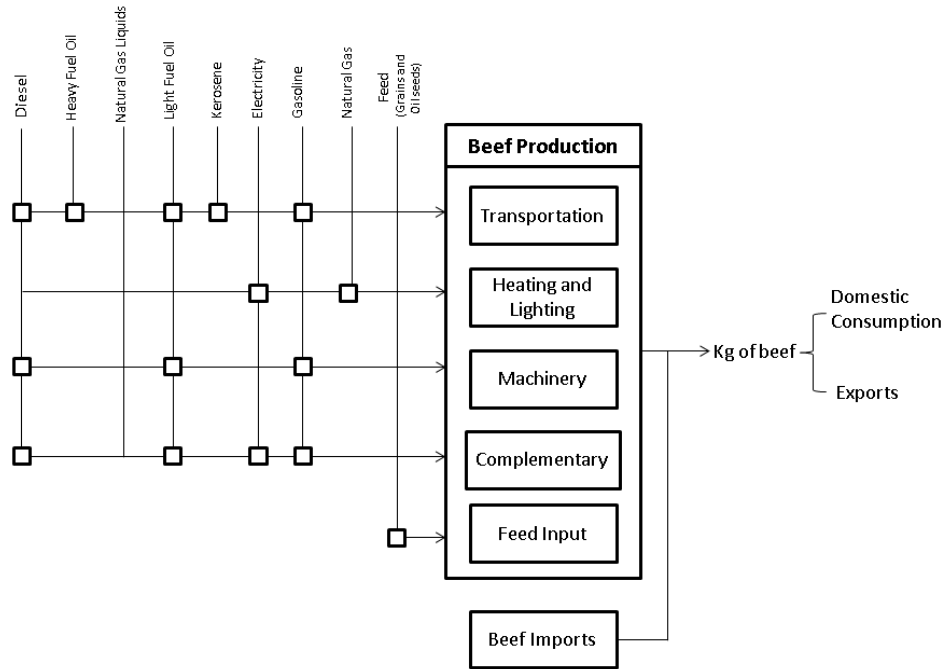


Figure 2: RES for the beef sub-sector

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 domestic consumption and net exports of agricultural products for each year of the analysis (2007 to 2030) and the agricultural production constraints imposed on the model are defined as the sum of these two components; thus 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, half, and two-thirds by the year 2030. In other words, consumption is progressively and linearly reduced from 2007 to 2030, with the year 2030 representing 33%, 50%, and 66%, respectively, of the initial 2007 consumption level. More precisely, we consider 33% as our basic assumption. The other two levels (50% and 66%) will be considered through a sensitivity analysis (see Section 6.4). 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 the reduction levels is justified in the following way. 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. Table 7 compares our reduction rates with the ones employed in the literature. We can see that our lower levels of reduction rate, 33% and 50%, are in line with what is used in the literature, and recall that our last reduction rate (66%) is only used for our sensitivity analysis.

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 2007 to 2020 is directly taken from these projections and years 2021 to 2030 were estimated by using the average growth rate from years 2007 to 2020.

Table 7: 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
Tukker et al. (2011)	40%	Static Analysis	Europe	Beef
Scarborough et al. (2012a)	50%	Static Analysis	UK	Livestock Products
The present study	33, 50, 66%	2007–2030	Canada	Livestock Products
Msangi and Rosegrant (2012)	50%	2010–2030	World	Livestock Products
Stehfest et al. (2009)	100%	2000–2050	World	Livestock products

5.2 Beef consumption reduction scenario (B)

The consensus in the literature is that beef is the most polluting and energy intensive agricultural product; Carlsson-Kanyama, Ekström and Shanahan (2002), Pimentel and Pimentel (2003), Eshel and Martin (2006), Carlsson-Kanayama and Gonzalez (2009), Carlsson-Kanyama and Faist (2011), Environmental Working Group (2011), and therefore, our first scenario consists of progressively and linearly reducing Canadian beef consumption until consumption is substituted by the specified level (33%, 50%, or 66%) 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.

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

Beef, pork and poultry consumption is progressively reduced until 2030. 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 has been calculated from Table 1 in Pimentel and Pimentel (2003) and is presented in Table 8.^{6,7}

Table 8: Caloric substitution of meat consumption by different agri-food categories

	Agricultural Product					
	Food Grains	Vegetables	Fruit	Dairy	Eggs	Total
% Increase for a lacto-ovo-vegetarian diet	59%	18%	1.5%	18%	3.5%	100%

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

Beef, pork, poultry, egg and dairy consumption is progressively reduced until 2030. Consumers are here assumed to substitute egg and dairy by grain and vegetable consumption.⁸

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. This enables the delineation of the environmental impact of meat and dairy product exports by contrasting results with our domestic consumption reduction scenario. Table 9 shows the percentage of meat and dairy production exported in 2009 (Statistics Canada, 2011).

⁶ Relative increases in non-meat products from the lacto-ovo-vegetarian diet have been taken from Table 1 in Pimentel and Pimentel (2003) in order to calculate caloric substitution amounts.

⁷ Pimentel and Pimentel (2003) address US food consumption patterns which were deemed applicable to the Canadian context due to both countries' socioeconomic resemblances.

⁸ In the same manner as with Table 8, caloric substitution for the BPPED scenario has been derived from Table 1 in Pimentel and Pimentel (2003).

Table 9: Proportion of production exported in 2009

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

These four policy scenarios (B, BPP, BPPED, iBPPED) impose constraints on the production of agricultural products, which are shown in Figures 3 and 4 for the year 2030 for a 33% reduction rate. Figure 3 shows the agricultural production, in million metric tonnes (MMT) imposed by the different policy scenarios for the following sub-sectors (in order of production level in the reference scenario): dairy, vegetables, hog, beef, poultry, fruit and egg. 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.

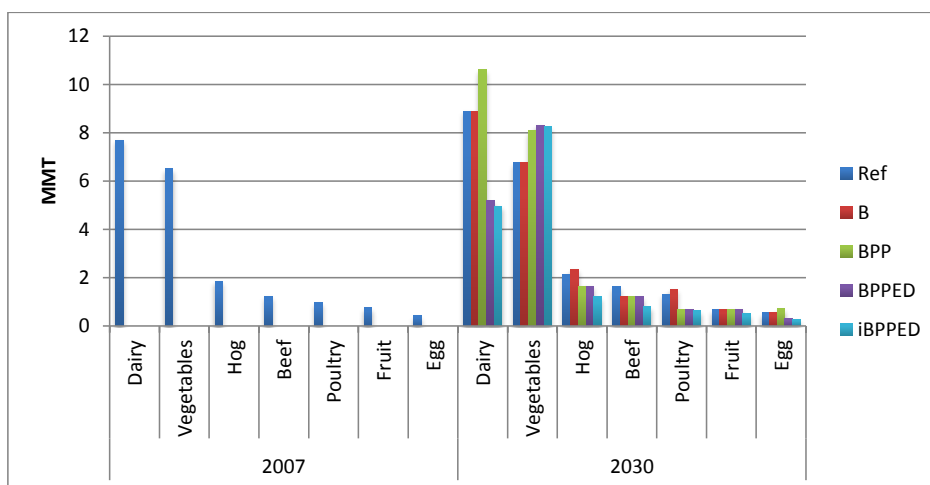


Figure 3: Agricultural production for our different scenarios in the year 2030

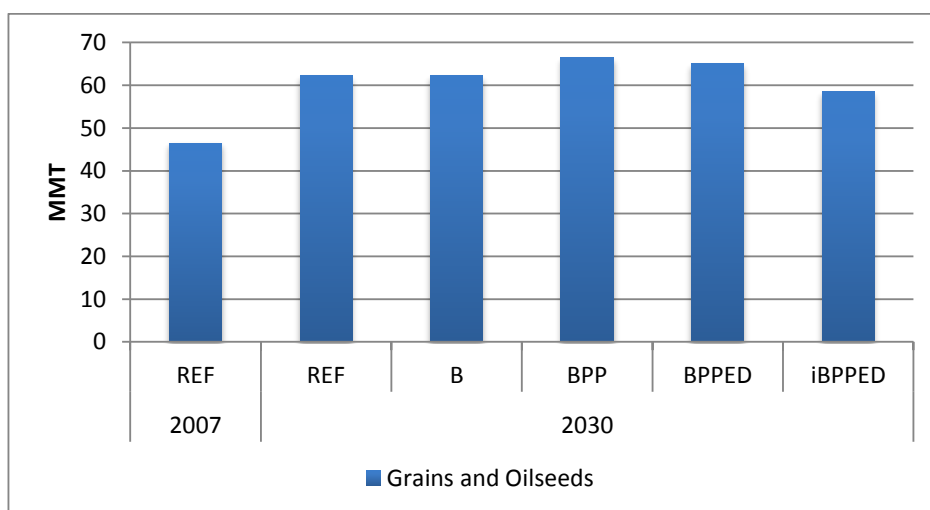


Figure 4: Grains and oilseeds production for our different scenarios in the year 2030

Figure 4 shows the production levels of grains and oilseeds for the year 2030 for our different policy scenarios.⁹ The variance in production levels across scenarios is explained by two factors related to meat and

⁹ They are shown in a different figure because of the significantly higher order of magnitude of grains and oilseeds production.

dairy consumption. 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.

6 Results

This section shows the results for our five different scenarios introduced in the previous section (REF, B, BPP, BPPED and iBPPED). All results shown before the summary Tables 11 and 12 are for a 33% reduction rate; since the results did not change considerably for the three different reduction rates (33%, 50% and 66%), presenting some results for only one of these reduction rates, 33%, the most realistic one, provided a clearer picture of the main conclusions. Subsequently, summary results are shown in Tables 11 and 12 for the three different reduction rates (see Section 6.4) in order to show the responsiveness of energy usage and greenhouse gas emission reductions with different meat and dairy consumption reduction amounts for our different scenarios.

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 insignificant when compared to the aggregated activity of 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 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 only. However, the LCA literature suggests that the agricultural sector is responsible for the majority of the impact on energy consumption and GHG emissions for meat and dairy consumption reduction policies, see, for instance, the coefficients estimated in Carlsson-Kanyama, Ekström and Shanahan (2002), Carlsson-Kanyama and Gonzalez (2009), and the Environmental Working Group (2011); which are summarized in Tables 5 and 6 (Section 3.6). In other words, our approach should capture the majority of the expected impacts.

6.1 Final energy consumption

Figure 5 reports on the breakdown of final energy consumption by end-use sector for our baseline scenario. 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. Indeed, this highlights the need for such a policy to be relatively low cost and possibly tied to other public benefits in order to be justified. This reality is why the link to public health is crucial for implementing such a policy. Low cost can be achieved if consumers motivate their consumption changes in order to benefit their personal health. Additionally, resulting lower public healthcare costs can prove to be significant collective benefits.

Now, looking more closely at the agricultural sector, Figure 6 shows the final energy consumption for three different fuel types: natural gas and NGLs (natural gas liquids), 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 the 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. This decrease in the share of oil primarily reflects the changing price ratio between oil and natural gas. Indeed, the increased extraction of unconventional gas sources and rising

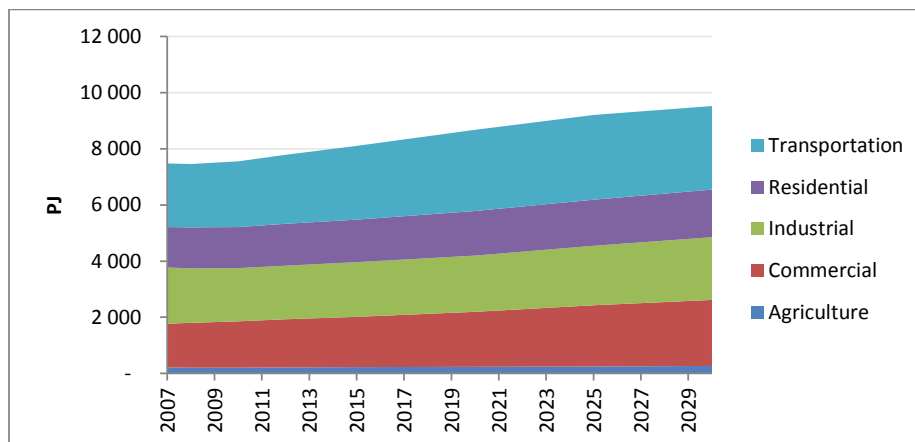


Figure 5: Final energy consumption by end-use sector in the baseline scenario, 2007–2030

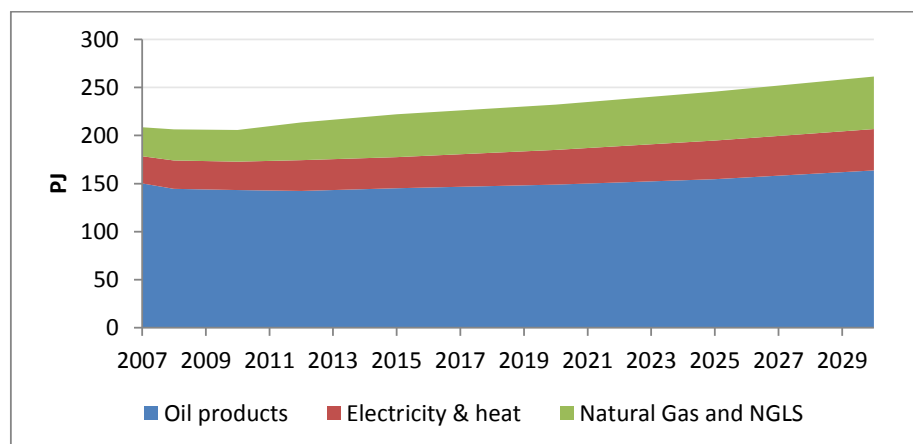


Figure 6: Final energy consumption by fuel in the agricultural sector, for the baseline scenario, 2007–2030

oil prices are both reflected in TIMES-Canada and lead to this progressive substitution of oil by natural gas.¹⁰

Figure 7 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.¹¹ This substitution leads to the higher aggregate energy consumption (see Figure 7). As expected the most constraining meat and dairy consumption reduction policy scenarios are the ones with the lowest aggregate energy consumption. Indeed, in the year 2030, the beef, pork, poultry, egg and dairy (BPPED) reduction scenario and the international BPPED (iBPPED) scenario lead to 15% and 29% less energy consumption, respectively, when compared to our baseline scenario.

¹⁰ We acknowledge that future oil prices are very uncertain as observed with recent prices (from over \$100 to below \$30 in recent years). If oil prices stay constant or decrease in the long-term as oppose to the predicted rise (NEB, 2016), we would expect more oil consumption and less natural gas consumption in our reference scenarios, leading to higher GHG emissions in our results due to more oil based agricultural processes being used.

¹¹ Most of the caloric substitution of pork and poultry comes from dairy products (see Table 8) which have significantly lower calories per kilogram consumed than meat products (see Table B1 in Appendix B). Therefore, the increase in dairy production must be larger than the decrease in poultry and pork production in order to compensate for the lower calorie count and this leads to the slightly higher energy totals seen in Figure 7.

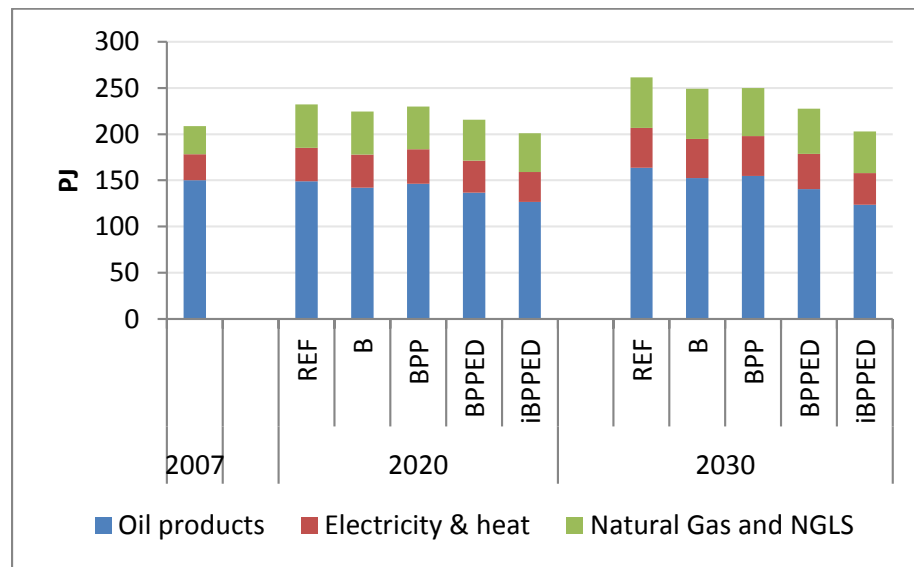


Figure 7: Final energy consumption by fuel in the agricultural sector, for the different scenarios, 2007–2030

The relative change from the baseline scenario for each type of fuel is shown in Figure 8 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 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 leads to a 7% decrease in agricultural consumption of oil products.

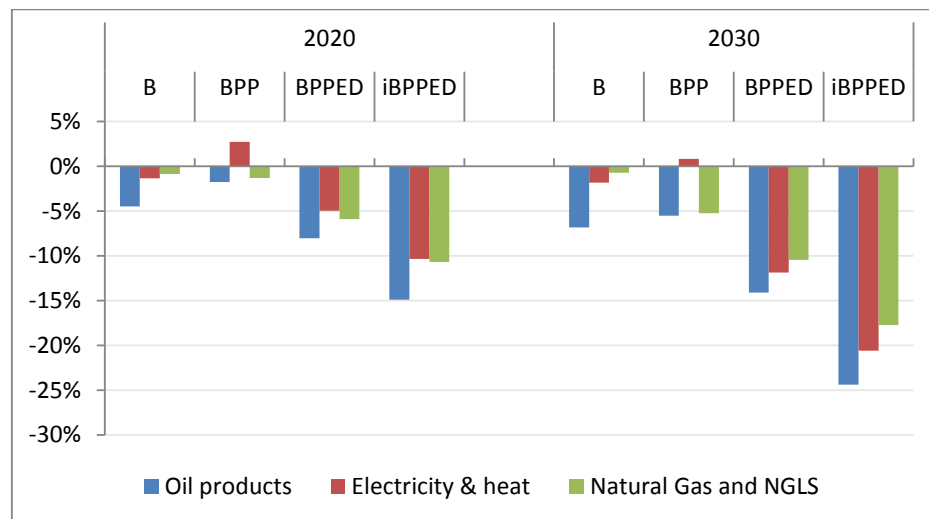


Figure 8: Percentage difference in agricultural sector energy consumption for B, BPP, BPPED iBPPED compared to REF, 2007–2030

6.2 GHG emissions

The results for total Canadian GHG emissions are displayed in Figure 9 for our baseline scenario and our four policy scenarios. We can see that our first three scenarios (B, BPP and BPPED) have little effect on total Canadian GHG emissions; they average for a decrease of around 13 million tonnes of CO₂ equivalent

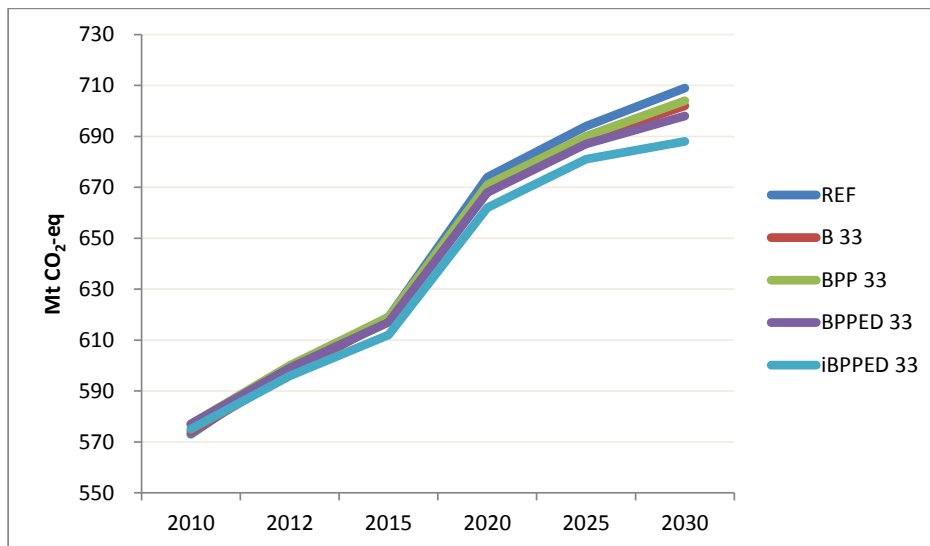


Figure 9: Canadian GHG emissions for the different scenarios, 2007–2030

(Mt CO₂-eq) 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 CO₂-eq. This means that around 14 MtCO₂-eq can be tied to foreign demand for meat and dairy agricultural products, more than what is tied to purely domestic consumption (13 Mt CO₂-eq).

Figure 10 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 6, 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.

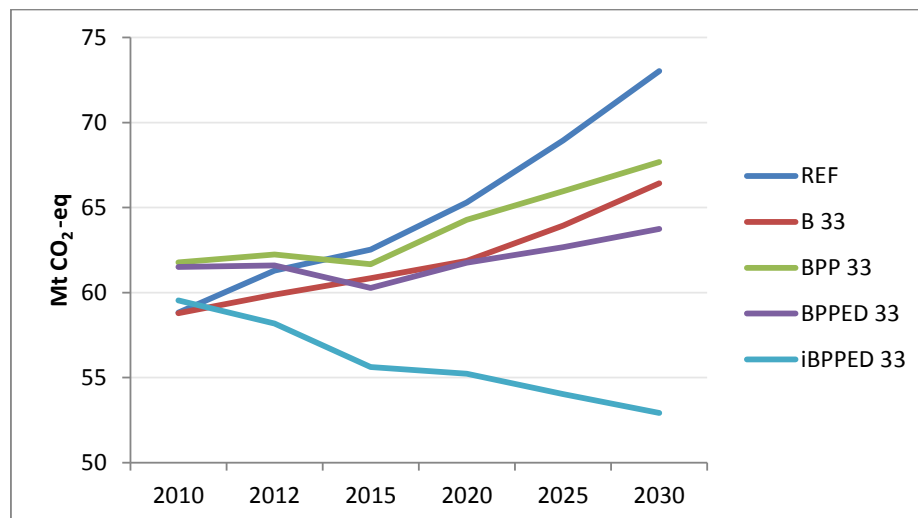


Figure 10: GHG emissions from the agricultural sector for the different scenarios, 2007–2030

6.3 Total cost

TIMES-Canada minimizes the total energy system cost (objective function) subject to different constraints, environmental or other, specified by the modeller. Technologies are chosen to satisfy the specified energy demand while minimizing this cost. Table 10 shows the percentage change in total energy system cost when compared to our baseline scenario for years 2007 to 2030; note that the order of magnitude for a 0.1% increase in total system cost is 10^9 dollars. It is interesting to see that there is no direct relationship between the number of products reduced and the size of the change in cost. For example, BPPED restricts more products than the BPP and B scenarios. However, the substitution of eggs and dairy by grains and vegetables causes an increase in cost for the BPPED scenario; the technologies employed to satisfy the increased demand of vegetables and oilseeds have an increased cost when compared to consumption in the BPP and B scenarios.

Table 10: Percentage change in total energy system cost when compared to the baseline scenario

Scenario	2030
B	0.028%
BPP	-0.015%
BPPED	0.063%
iBPPED	-0.099%

6.4 Sensitivity analysis

Tables 11 and 12 show the results for our scenarios with the one-third reduction policy, additionally results for sharper consumption reduction policies, of 50% and 66%, are shown to illustrate the responsiveness of energy demand reduction and GHG emission reduction for a change in the reduction rate. It is interesting to see that total GHG emissions for the BPPED and iBPPED scenarios do not decrease as the reduction rate increases. This is due to the substitution of eggs and dairy by grains and vegetables. This substitution exhibits decreasing returns to scale in the sense that increasing the severity of the reduction rate leads to inefficient levels of grain production requiring higher energy usage than in scenarios with lower reduction rates. The increased energy usage (see Table 12) leads to the higher energy related GHG emissions seen in Table 11.

Table 11: Total Canadian GHG emissions for all scenarios and reduction rates

Scenario	Total Canadian GHG emissions (MtCO ₂ -eq)					
	2010	2012	2015	2020	2025	2030
REF	571	600	621	674	694	709
B 33	571	599	619	671	690	704
B 50	571	598	618	670	688	701
B 66	571	598	617	668	686	697
BPP 33	574	600	618	670	689	702
BPP 50	574	600	618	669	688	700
BPP 66	573	599	616	667	685	696
BPPED 33	574	600	617	668	687	698
BPPED 50	574	600	617	668	688	698
BPPED 66	574	600	617	668	688	699
iBPPED 33	572	596	612	662	681	688
iBPPED 50	572	596	612	662	682	689
iBPPED 66	572	596	612	662	680	689

6.5 Health impact

Friel et al. (2009) provide estimates for the health benefits tied to reducing meat and dairy consumption, highlighting the fact that the benefits of such dietary changes are not limited to reduced GHG emissions. We use the results from this study to illustrate possible health effects of a meat and dairy consumption reduction policy for the Canadian context. The choice of their study as a reference for ours is due to similarities between both. First, Friel et al. (2009) study the health changes for the United Kingdom, where health and

Table 12: Total agricultural sector energy usage

Scenario	Total agricultural sector energy usage (PJ)					
	2010	2012	2015	2020	2025	2030
REF	207	216	225	235	248	263
B 33	206	214	221	228	239	251
B 50	207	214	219	226	235	246
B 66	206	213	218	223	231	241
BPP 33	212	215	217	223	233	243
BPP 50	211	214	215	221	230	239
BPP 66	211	213	214	219	225	233
BPPED 33	211	212	212	214	219	225
BPPED 50	211	212	212	215	220	226
BPPED 66	211	212	212	215	220	227
iBPPED 33	207	205	201	200	200	201
iBPPED 50	207	205	201	201	201	202
iBPPED 66	207	205	201	201	201	203

socioeconomic characteristics (for example: age structure, mortality rates, income distribution, food prices for different agri-food categories compared to household income, etc.) are similar to the Canadian context.^{12,13} Additionally, their results are based on a 30% reduction of animal product consumption by 2030, which is very similar to our BPPED scenario (33% reduction in the consumption of all animal products by 2030). Their results indicate that such a dietary change in the UK could lead to a 16% decrease in years of life lost and a 17% decrease in premature deaths due to the reduced intake of saturated fats (from reducing consumption of animal products). Considering the aforementioned similarities, such significant health benefits, in terms of reductions in years of life lost and premature deaths, could also be achieved with a similar meat and dairy consumption reduction policy in Canada.

6.6 Comparison of results

GHG emission reduction levels attained through our scenarios are similar to results found in the literature see for instance: Friel et al. (2009), Tukker et al. (2011), and Scarborough et al. (2012a). Mainly, the emission reductions achieved in the agricultural sector is considerable, from around 10% to 40% reduction depending on the severity of the scenario. However, for developed countries, agricultural sectors typically represent a relatively small amount of the country's total emissions; for example, 8% for Canada (Environment Canada, 2012) and 9% for the UK (Friel et al., 2009); which leads to relatively small country-wide GHG emission reductions. Additionally, for energy usage, to our knowledge, no other study has provided national level energy usage results with this level of detail for this type of temporal horizon, therefore, no comparable are presented.

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 agricultural energy consumption and GHG emissions. We contrasted four different consumption reduction policies with a baseline scenario. The scenarios employed in the analysis span until 2030 and differ in the scope of their consumption restrictions and three different reduction amounts were used: 33%, 50% and 66% reduction of consumption by the year 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.

¹² See Table B2 in Appendix B for a comparison of main health characteristics between Canada and the UK.

¹³ Both members of the G7, these two countries have in particular similar Gini inequality coefficients (measure of income disparity in a country); see: www.conferenceboard.ca/hcp/details/society/income-inequality.aspx. Additionally, groceries prices are comparable (less than a percentage point difference); see: www.numbeo.com/cost-of-living/compare_countries_result.jsp?country1=Canada&country2=United+Kingdom.

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. 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).

Our analysis shows that the effect of our consumption reduction policy scenarios is considerable within the agricultural sector and significant when considering total Canadian energy consumption and GHG emissions. However, the justification of implementing such policies could be difficult when solely considering environmental benefits, especially when taking into account the importance of the livestock sector to the Canadian economy and the fact that the most impactful scenario was one where exports of livestock products were reduced by one third by 2030 (iBPPED). However, using the findings from other studies focusing on the negative health impacts of meat-based diets, we have inferred that a reduction in the consumption of meat and dairy products, in line with one of our moderate scenarios, could result in a considerable decrease in years of life lost and premature deaths by the year 2030. This could provide a low-cost way of implementing the agri-food consumption pattern restrictions if diet modifications can be motivated by the individuals themselves as a way of improving their own health, however, relying on individual level changes through information provision based strategies remains a challenge. Additionally, 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, could justify the implementation of meat and dairy consumption reduction policies.

Appendix A – Energy usage coefficients for 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	–
<i>Transport</i>	–	–	–	0.09	–	–	0.03	–
<i>Machinery</i>	–	–	–	0.03	–	–	0.53	–
<i>Heating and Light</i>	0.02	–	–	–	0.01	–	–	–
<i>Complementary</i>	0.01	–	–	–	–	–	–	–
<i>Non-Farm</i>	0.02	–	–	0.03	0.01	–	0.01	–
DAIRY	0.65	–	0.01	0.51	0.32	0.01	1.37	–
<i>Transport</i>	–	–	–	0.32	–	–	0.05	–
<i>Machinery</i>	–	–	–	0.10	–	–	1.29	–
<i>Heating and Light</i>	0.37	–	–	–	0.18	–	–	–
<i>Complementary</i>	0.10	–	–	–	0.02	–	0.03	–
<i>Non-Farm</i>	0.17	–	–	0.09	0.11	–	–	–
CATTLE	5.55	0.01	0.08	9.72	2.92	0.21	22.76	0.02
<i>Transport</i>	–	0.01	0.01	5.64	–	–	2.50	–
<i>Machinery</i>	–	–	0.07	1.94	–	–	19.80	0.02
<i>Heating and Light</i>	2.44	–	–	–	0.96	0.07	–	–
<i>Complementary</i>	0.78	–	–	0.19	0.15	0.01	–	–
<i>Non-Farm</i>	2.33	–	–	1.94	1.81	0.13	0.46	–
HOG	2.52	–	0.01	1.53	1.62	0.03	3.39	–
<i>Transport</i>	–	–	–	0.95	–	–	0.17	–
<i>Machinery</i>	–	–	0.01	0.29	–	–	3.19	–
<i>Heating and Light</i>	1.63	–	–	–	0.97	0.02	–	–
<i>Complementary</i>	0.10	–	–	0.03	0.13	–	0.03	–
<i>Non-Farm</i>	0.78	–	–	0.26	0.52	0.01	–	–
POULTRY	2.98	–	0.01	1.02	4.18	0.03	2.58	–
<i>Transport</i>	–	–	–	0.60	–	–	0.90	–
<i>Machinery</i>	–	–	0.01	0.08	–	–	1.50	–
<i>Heating and Light</i>	2.23	–	–	–	3.43	0.02	–	–
<i>Complementary</i>	0.27	–	–	0.06	0.04	–	0.18	–
<i>Non-Farm</i>	0.48	–	–	0.28	0.71	–	–	–
EGGS	1.49	–	–	0.51	2.09	0.01	1.29	–
<i>Transport</i>	–	–	–	0.30	–	–	0.45	–
<i>Machinery</i>	–	–	–	0.04	–	–	0.75	–
<i>Heating and Light</i>	1.12	–	–	–	1.72	0.01	–	–
<i>Complementary</i>	0.13	–	–	0.03	0.02	–	0.09	–
<i>Non-Farm</i>	0.24	–	–	0.14	0.36	–	–	–
FRUIT	0.33	–	–	0.22	0.11	–	0.52	–
<i>Transport</i>	–	–	–	0.10	–	–	–	–
<i>Machinery</i>	–	–	–	0.06	–	–	0.44	–
<i>Heating and Light</i>	0.13	–	–	–	0.02	–	–	–
<i>Complementary</i>	0.08	–	–	–	0.01	–	0.08	–
<i>Non-Farm</i>	0.12	–	–	0.06	0.09	–	–	–
VEG	0.11	–	–	0.07	0.04	–	0.17	–
<i>Transport</i>	–	–	–	0.03	–	–	–	–
<i>Machinery</i>	–	–	–	0.02	–	–	0.15	–
<i>Heating and Light</i>	0.04	–	–	–	0.01	–	–	–
<i>Complementary</i>	0.03	–	–	–	–	–	0.03	–
<i>Non-Farm</i>	0.04	–	–	0.02	0.03	–	–	–

Appendix B

Table B1: Energy obtained from eating different food types, kcal per kg of product, derived from Pimentel and Pimentel (2003)

	Agricultural product							
	Beef	Pork	Chicken	Eggs	Dairy	G&O	Fruit	Vegetables
kcal per kg	3.65	3.65	3.65	3.79	1.50	7.45	1.12	0.62

Table B2: Health indicators for Canada and the UK (Source: WHO; <http://apps.who.int/gho/data>)

Indicator	Canada	Canada	United Kingdom	United Kingdom
	2013	2012	2013	2012
Population proportion under 15 (%)	16.4	16.37	17.4	17.54
Population proportion over 60 (%)	21.3	20.82	23.2	23.06
Population median age (years)	40.1	39.99	40.2	40.07
Mortality rate	–	372	–	409

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