10-Year Changes of Food Consumption and Carbon Footprint in Ontario

by

Basak Topcu

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

What humans eat can have a significant impact on ecosystems and the climate. In order to attain the climate targets to keep global warming below 1.5 degrees Celsius, it is important to reduce consumption of carbon-intensive food products. Many studies have quantified the environmental impacts of food consumption. However, most of these prior diet-related environmental assessment studies have evaluated impacts based on a snapshot of food consumption, instead of evaluating the changes in food-related environmental impacts over a period of time. Understanding these changes is important in determining what factors affect consumer food consumption behaviours that would shift their food consumption patterns towards less resource intensive products.

This thesis evaluates the changes in food, nutritional value, and carbon footprint (CF) of dietary patterns in Ontario in the last decade, broadly in three steps. First, change assessment is conducted by comparing the overall food consumption based on the 24-hour recall food intake data from the Canadian Community Health Survey-Nutrition in 2004 and 2015. Then seven dietary patterns are identified by analyzing the food types of each survey participant and Life Cycle Assessment is used to quantify CF of these dietary patterns. Canada's Food Guide is used to assess the nutritional quality of actual dietary patterns, and then alternative nutritionally-balanced and low carbon dietary patterns are formulated and their CF is determined.

The results suggest that: 1) overall, Ontarians are eating less red meat and more poultry and drinking less beverages high in sugar content; 2) Ontarians continue to overconsume daily protein, possibly because they do not consider protein from non-meat products, such as milk and cheese; 3) the CF of Ontarians food consumption has decreased in the last decade, specifically due to reductions in beef, which is the most carbon-intensive food product; and 4) also, the CF of nutritionally-balanced diets has decreased for all dietary patterns, only exception is Pescatarian that showed a slight increase.

Changes in types and amounts of food consumed could be a result of health concerns, increase in climate change awareness, economic or cultural fluctuations. Overall, this thesis improves our understanding of the CF and nutritional assessment of Ontarians' current food consumption and how this has changed in the last 10 years. By determining and understanding changes, this research could also be helpful to identify strategies to shift Ontarians' food consumption behaviors towards nutritionally-balanced and low carbon-intensive food choices.

KEY WORDS: Canada, change, carbon footprint, life cycle assessment, food consumption, dietary pattern, nutrition, greenhouse gas emission

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Dedication

I dedicate this thesis to all living beings who have pursued or contributed to achieving a clean air, water and soil for a sustainable life in the past, now and in the future.

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List of Abbreviations

AC – Acidification

CCHSN – Canadian Community Health Survey - Nutrition

CF – Carbon footprint

CO_2 eq – Carbon dioxide equivalent

DPG – Dietary pattern food group

EU – Eutrophication

FAO – Food and Agriculture Organization for the United Nations

FBS – Food balance sheet

FFQ – Food frequency questionnaire

FU – Functional Unit

GHG – Greenhouse gases

GHGE – Greenhouse gas emissions

GWP – Global warming potential

HLG – High-level food group

LAFA – Lost Adjusted Food Availability

LCA – Life Cycle Assessment

LLG – Low-level food group

NS – National statistics

RF – Reference flow

SRS – Self-reported survey

USDA – United States Department of Agriculture

Chapter 1 Introduction

Climate change is one of the most serious dangers that is threatening the survival of all living beings on earth. There is overwhelming scientific consensus that the planetary boundaries of greenhouse gases (GHG), biodiversity loss, and nitrogen-cycle have already surpassed their secure levels that keep our planet habitable (Rockström & et.al., 2009). It is well known that these disastrous changes to the environment are caused by anthropogenic activities. Perhaps the most fundamental of human activities is food consumption, which has a direct and surprisingly high impact on the environment (Ericksen, 2008). Currently, the global agriculture sector is estimated to emit 24% of total global GHG (IPCC, 2014), utilize 70% of planet's total available fresh water (FAO, 2016), and occupy 30% of arable lands (Ramankutty, Evan, Monfreda, & Foley, 2008). Four main factors are expected to increase the agricultural pressure on the environment: population growth, income growth, food consumption, and climate change.

The current estimates indicate that by 2050 the world's population will grow by 29%, reaching 9.7 billion (United Nations, 2015b). By 2050, the world's GDP will grow by 230%, and as the affluence of countries increases, the demand for more food products will grow (OECD, 2017). Current dietary patterns are shifting towards animal-based food products (Tilman & Clark, 2014), which are resource-intensive, specifically very high in GHG, water and land use (Kearney, 2010). Finally, climate change is creating extreme weather conditions leading to increasing droughts and floods, which affect food production and food security (Ericksen, 2008). Thus, expanding agricultural activities would result in increasing GHGs, deforestation, degradation of land, biodiversity loss, and freshwater use (Ramankutty et al., 2018).

The United Nations (UN) Sustainable Development Goals (SDG) highlight the importance of increasing sustainability of anthropogenic activities (United Nations, 2015a). Out of the 17 SDGs, 5 focus on the environment, one of which is responsible consumption and production (SDG 12). Agricultural pressure on the environment could be decreased either through sustainable agricultural production, e.g., better water management through technological improvement and less pesticide and fertilizer use, or through sustainable consumption, e.g., shifts towards less resource-intensive food products. Thus, changing the consumption habits of consumers, i.e., their dietary patterns, could be an effective way of reducing environmental resource consumption of agriculture (Ericksen, 2008; Kearney, 2010).

Besides its impacts on planet's health, food consumption is directly related to humans' health. The amount and types of food consumed can result in *non-communicable diseases* (NCD), which are chronic diseases that are caused by lifestyle, environment and genetic inheritance. For example, red and processed meat consumption are highly associated with NCDs, such as cardiovascular disease and cancer (American Institute for Cancer Research & World Cancer Research Fund, 2007). Overall 70% of all total global deaths are due to NCDs (NCD Allicance, 2017), so shifting towards nutritionally-balanced diets that have low environmental impacts would benefit humans health (FAO, 2018).

In Canada, studying the link between food consumption and environmental impacts is a growing area of research. A recent study in Canada using 2004 food intake data showed that residents of Ontario could reduce their carbon impacts by consuming less carbon-intensive foods, such as beef, without actually eliminating any preferred foods (Veeramani, Dias, & Kirkpatrick, 2017). This thesis builds on this research by addressing the following research question: *How have the changes in food consumption and dietary patterns from 2004 to 2015 affected Ontario's carbon footprint?*

Specific objectives of the thesis are as follows:

1. *Determine changes in Ontarians' food consumption and dietary patterns from 2004 to 2015.*
2. *Assess changes in Ontarians' nutritional intake of dietary patterns from 2004 to 2015.*
3. *Quantify the carbon footprint of each 2015 food basket formulated.*

This thesis contributes to an understanding in carbon footprint (CF) of Ontarians' current food consumption and how this has changed in the last 10 years while considering nutritional aspects. The findings of this study will inform policy-makers, food sector and consumers about the recent changes in food consumption and its implications on the health of environment and humans. By determining and understanding changes, this research could also be helpful to identify strategies to shift Ontarians' food consumption behaviors towards nutritionally-balanced and low carbon-intensive food choices.

1.1 Outline of Thesis

This thesis is organized as follows:

- The rest of Chapter 1 gives background information about Canadian food sector and literature review on environmental impacts of dietary patterns.
- Chapter 2 provides a detailed explanation about how this research is conducted in order to answer the research question and the specific objectives. Briefly, this chapters explains: (i) the Canadian Community Health Survey – Nutrition that provides the data studied; (ii) methods used to quantify food consumption and identify dietary patterns; and (iii) Life Cycle Assessment (LCA) tool used to quantify the CF of formulated food baskets.
- Chapter 3 presents the results of analysis conducted to answer the research question and specific objectives. This chapter demonstrates the 10-year change of food consumption, dietary patterns, nutritional intake of dietary patterns and CF of formulated food baskets for each dietary pattern.
- Chapter 4 reviews the main findings of this thesis and concludes by providing recommendations for policy-makers, businesses and consumers and identifying future work suggestions.

1.2 Background

1.2.1 Food System in Canada and Its Impacts on Environment

Canada is one the largest agricultural producers and the fifth-largest exporter in the world (Agriculture and Agri-Food Canada, 2016a). The top five commodities produced by weight are wheat, rapeseed, corn, barley, and cow milk (FAOSTAT, 2018). The percentages of exported amounts are as follows: 50% of beef, 70% of soybeans, 70% of pork, 75% of wheat, 90% of canola and 95% of pulses (Canadian Agri-Food Trade Alliance, 2018). Canadian domestic food production provides 70% of total food consumed in Canada (Statistics Canada, 2016). The top five imported commodities by weight that make 71% of total imported food products are grains, fruits, vegetables, oils and sugar (Kissinger, 2012). These products are imported from various places, such as USA, Mexico, Latin America, Asia, Europe and others (Kissinger, 2012). Within Canada's economy, agri-food system generated 6.6% of total GDP and provided jobs for one in every eight person (Agriculture and Agri-Food Canada, 2016a). This sector ranked second in the consumers' expenditure after housing (Statistics Canada, 2017e).

Considering the entire food supply chain, Canadian food system has high potential to lower agricultural pressure on the environment (MacRae, Cuddeford, Young, & Matsubuchi-Shaw, 2013; Veeramani et al., 2017). For example, the food waste alone is very significant. It is estimated to be 40%

of food produced in Canada is lost along the food supply chain (Uzea, Gooch, & Sparling, 2013). Among all different stages of the food supply chain, largest food loss occurs at consumer level (Uzea et al., 2013). In the Paris Climate Agreement, Canada pledged to reduce its GHGE 4% below 1990 emissions by 2030 (Climate Action Tracker, 2018). The current GHGE trends based on recent policies show that by 2030 GHGEs will be at least 28% above than the pledged targets for 2030 (Climate Action Tracker, 2018). Since 1990, GHGE of agriculture has increased by 21% and currently contributes 10% of total GHGEs in Canada (Stats Canada 2017). If all activities within food systems, such as production, processing, transportation, and storage are considered, the contribution of agriculture increases from 10% to around 20% (Garnett, 2011; MacRae et al., 2013).

Agricultural pressure on freshwater resources is significant in Canada. Canada has 7% of world's total freshwater resources (Government of Canada, 2009), yet also Canada has the second highest freshwater consumption per capita in the world (Environment and Climate Change Canada, 2016). Similar to global trends, 70% of total freshwater consumption in Canada is due solely to agriculture (Government of Canada, 2008). Ensuring accessibility of secure drinking freshwater is a human right (United Nations, 2002, 2010), and consuming water sustainably is the responsibility of all human beings including Canadians. In order to consume its freshwater resources sustainably, Canada invests in improving the efficiency of water usage, the availability and quality of freshwater resources with the cleaning projects of Great Lakes, and Lake Winnipeg (Government of Canada, 2007, 2013). However, current investments are not enough to lower Canadians' agricultural pressure on the freshwater resources.

Agricultural activities only occupies 7% of total land areas in Canada, where arable land area is estimated to around 70% (Statistics Canada, 2017b). Broadening land use of agricultural activities would lead to more deforestation and biodiversity loss, and less soil and water quality. Despite this danger, it is worth noting that Canada uses some of the best management practices and technologies that increases production yields while minimizing land-use and other agricultural pressure on the environment (Statistics Canada, 2017c).

1.2.2 Ontario Background: Demographics and Food Systems

Among all other provinces in Canada, Ontario has the highest population with 13,789,000 dwellers that represent approximately 40% of total Canadian population (Statistics Canada, 2017d). Ontarians have a very diverse ethnic background. Around 70% of Ontarians have non-Canadian ethnic origins (Ontario Ministry of Finance, 2013) and this multicultural characteristics of Ontario increases demand of different types of imported food products. Therefore, population of Ontario portrays 40% of Canada's population while illustrating diverse food consumption.

In terms of land, Ontario has the second largest area and is known for its high agricultural production. Food production and processing in Ontario represent 25% of total revenue generated from agricultural activities in Canada (National Farmers Union, 2011). This province provides nearly all soybeans and tobacco grown in Canada (National Farmers Union, 2011), and also half of Canada's corn (National Farmers Union, 2011). Compared to other provinces, Ontario has a significant amount of production of vegetables, fruits, poultry, pigs and cattle (National Farmers Union, 2011). Despite the vegetable and fruit production in Ontario (OMAFRA, 2018b), trade balance sheet reveals that Ontario highly depends on imported vegetables and fruits (OMAFRA, 2018a). Importantly, Ontario is the main center of greenhouse vegetable production and represents 69% of total greenhouse area in Canada (Agriculture and Agri-Food Canada, 2016b). Approximately 71% of greenhouse production occurs in Ontario and has increased by 20% in the last 5 years (Agriculture and Agri-Food Canada, 2016b). In Ontario, most commonly produced greenhouse products are tomatoes, peppers and cucumbers (OMAFRA, 2018b).

The Government of Ontario's strategy is to increase agriculture business sustainably and lower the agricultural pressure on the environment (OMAFRA, 2018c). Some examples of ongoing projects to obtain these goals are Going Forward 2, Ontario Local Food Strategy, and Sustaining Ontario's Agricultural Soils. Specifically, Going Forward 2 project funded events, tools and resources to grow agri-food business in the province. Ontario Local Food Strategy project aims to increase Ontarians access to local food by supporting local food sales. Sustaining Ontario's Agricultural Soils project's goal is to achieve healthy soil by 2030 through various soil improvement initiatives.

1.3 Literature Review: Life Cycle Assessment of Dietary Patterns

The literature review covers a brief overview of health and environmental implications of food consumption and the challenges of quantifying environmental impacts of diets by using life cycle-based methodologies since 2015. A previous thorough review of similar research before 2015 was covered by Veeramani (2015).

1.3.1 Health Implications of Diets

The food we consume has direct impacts on our health. Certain types of food are known to increase the risk of NCDs, such as cancer, diabetes, heart disease, and others. For example, high consumption of processed red meat increases the risk of having type 2 diabetes, cardiovascular disease (Boada, Henríquez-Hernández, & Luzardo, 2016) and colorectal cancer (WHO, 2015). Under or over consumption of food beyond what is required in energy (calories) can result in malnutrition (WHO, 2018). Furthermore, a variety of foods consumed is important for health as different food products have different amounts and types of macronutrients and micronutrients (FAO, 2010). For example, consuming vegetables in high amounts is recommended to achieve healthy diets (Harvard School of Public Health, 2012), however consuming only vegetables in a diet might lead to fatigue due to lack of protein, zinc and B-vitamins (Harvard Health, 2017; Rogerson, 2017).

Nevertheless, only a few studies have assessed the environmental and individual health implications of diets. Downs & Fanzo (2015) evaluated the environmental impacts of cardio-protective diets, while (Hallström, Gee, Scarborough, & Cleveland, 2017; Milner et al., 2015; Tilman & Clark, 2014) studied the relative risk of NCDs and environmental impacts of analyzed diets. Therefore, this is an area of research that requires more study because food consumption has direct impacts on the health of individuals and indirect impacts on the environment through food production systems (Ericksen, 2008).

1.3.2 Environmental Implications of Diets

In the last 20 years, there have been an accumulating number of studies that consider the environmental implications of food consumption. Early studies investigated environmental impacts of individual food products, mostly focusing on production methods, while later studies mostly conducted in Europe focused on impacts of food consumed. The earlier studies were. In the last five years, the focus of these studies has been expanded to consider diets and other regions, such as USA, China, India, Brazil and Peru as shown in Table 1 (pg. 18). Very recently, a Canadian study on environmental impacts of diets was conducted (Veeramani et al., 2017). This study quantified the CF of dietary choices of Ontario's residents in 2004, by identifying seven different dietary patterns, and concluded that by shifting dietary choices to low-carbon and nutritionally-balanced diets Ontarians could lower Canada's CF. As people's dietary patterns can change over time, it is important to understand historical and current food consumption to inform policy-makers, businesses and consumers on how to reduce CF and other impacts.

National studies tend to focus on understanding environmental impacts of food consumption at the level of an entire population (Table 1). Those studies quantify the national water footprint (WF); Hess, Andersson, Mena, & Williams (2015) and Jalava et al. (2016), CF; Abeliotis, Costarelli, & Anagnostopoulos (2016), and multiple environmental impacts; Notarnicola, Sala, et al. (2017). Several national studies also investigate nutritional quality of diets and food waste. Conrad et al. (2018) associates environmental impacts of food consumption with diet quality, and Eberle & Fels (2016) quantifies environmental impacts of consumed food accounting food waste at all stages. By doing so, these studies provide insights to policy-makers, specifically at government level, about how to link diet and environmental impacts to lower the burdens on environment due to total national food sector activities, from production to consumption. National studies provide aggregated information of analyzed population, but these studies cannot understand different food choices of individuals or households.

In order to understand household and individual preferences of analyzed population, studies investigate household and individual food consumption. Both, household and individual studies focus on quantifying environmental burdens of food consumption considering socio-demographic characteristics of households or individuals, such as the education level, annual income, gender, or identified dietary patterns. Specifically, the focus of individual studies are mostly adults older than 18. Examples of studies analyzed households are Vázquez-Rowe, Larrea-Gallegos, Villanueva-Rey, & Gilardino (2017). Example of studies that focused on individuals are Biesbroek et al. (2014), Fresán, Martínez-Gonzalez, Sabaté, & Bes-Rastrollo (2018), Kramer, Tyszler, Veer, & Blonk (2017), Lacour et al. (2018), Seves et al. (2017), and Tyszler et al. (2014). Studies that focus on household and individual preferences give insights on consumers' behaviours and how these behaviours are correlated with certain demographic characteristics.

Table 1. Summary of reviewed dietary patterns studies since 2015 ordered by scale of analysis. GWP: Global warming potential, LU: Land use, WF: Water footprint, EU: Eutrophication, P: Phosphorous, N: Nitrogen

Reference	Environmental Impacts	Scale	Geography	Age	Nutritionally-Balanced Diets
Biesborek et al. (2018)	GWP	Individual	Netherlands	20 - 70	-
Fresan et al. (2018)	GWP & LU, WF & energy	Individual	Spain	18 - 25	-
Lacour et al. (2018)	GWP, LU & energy	Individual	France	adults	-
Vazquez-Rowe et al. (2017)	GWP	Individual	Peru	-	-
van de Kamp et al. (2017)	GWP	Individual	Netherlands	19 - 50	*Reference:* Wheel of Five 1) regular healthy, 2) sustainable healthy (SH), 3) SH w/o meat, 4) healthy w/o meat
Heller et al. (2018)	GWP & energy	Individual	USA	>18	-
Rosi et al. (2017)	GWP, WF & Ecological footprint	Individual	Italy	18 - 60	-
Hyland et al. (2017)	GWP	Individual	Ireland	18 - 87	-
Treu et al. (2017)	GWP & LU	Individual	Germany	14 - 80	-
Roos et al. (2015)	GWP, LU & Biodiversity loss	Individual	Sweden	-	*Reference:* - 1) Nordic Recommendations Diet, 2) Low Carbohydrate High Fat Diet
Temme et al. (2015)	GWP	Individual	Netherlands	7 - 69	-
Tom et al. (2016)	GWP, WF, & energy	Individual	USA	>19	*Reference:* USDA Food Pattern 1) Calorie-adjusted Diet, 2) Nutritionally-Balanced Diet, 3) Calorie-adjusted & Nutritionally-Balanced Diet
Milner et. al. (2015)	GWP	Individual	UK	-	*Reference:* WHO Nutrition Recommendation 7 Scenarios: 10% - 70% reduction in GHG in Nutritionally-Balanced Diet
Marije Seves et al. (2017)	GWP & LU	Individual	Netherlands	19 - 69	*Reference:* - 1) 30% reduction in meat, dairy and eggs, 2) 100% reduction in meat, dairy and eggs
De Laurentiis et al. (2017)	GWP & WF	Individual	England	Kids	-
Blas et al. (2018)	WF	Household	Spain	-	-
Song et al. (2017)	GWP	Individual	China	18 - 50	*Reference:* Chinese Nutrition Recommendations 9 scenarios: various reductions in meat and dairy
Kramer et al. (2017)	GWP, LU & energy	Individual	Netherlands	9 - 69	*Reference:* Dutch Food Recommendations 1) Optimized Nutritionally-Balanced Diet
Goldstein et al. (2017)	GWP, WF & LU	Individual	USA	-	*Reference:* - 3 scenarios: substitute meat with plant-based meat with 10%, 25% and 50%
Perignon et al. (2016)	GWP	Individual	France	>18	*Reference:* WHO Nutrition Recommendations 1) Optimized diet, 2) Optimized diet w/macro constraints, 3) Optimized diet w/all nutrient constraints
Tyszler et al. (2016)	GWP, LU & energy	Individual	Netherlands	31-50	*Refence:* - 1) Nutritionally-Balanced Diet, 2) Pescatarian Diet, 3) Vegetarian Diet, 4) Vegan Diet 5) Current Diet w/30% reduction in GHG, LU & energy
Ribal et al. (2016)	GWP	Individual	Spain	Kids	*Reference:* - Macronutrients and Micronutrients Optimized Diet

Reference	Environmental Impacts	Scale	Geography	Age	Nutritionally-Balanced Diets
Walker et al. (2018)	GWP & WF	Individual	7 EU countries	18 - 79	*Reference:* European Food Safety Authority Macronutrients and Micronutrients Optimized Diet
Notarnicola et al. (2017)	ILCD: 14 midpoint categories	Nation	EU-27 countries	-	*Reference:* - 1) 25% reduction in meat, dairy and eggs 2) 50% reduction in meat, dairy and eggs
Pairotti et al. (2015)	GWP & energy	Nation	Italy	-	*Reference:* Italian National Food Center 1) Mediterranean Diet, 2) Healthy Diet, 3) Vegetarian Diet
Jalava et al. (2016)	WF	Nation	Global	-	*Reference:* WHO Nutrition Recommendation 1) recommended diet (RD) 2) RD: 50% reduction in meat, dairy, & eggs, 3) RD: 25% reduction in meat, dairy, & eggs, 4) RD: 12.5% reduction in meat, dairy, & eggs, 5) Scenario 1 + 50% reduction in food loss 6) Scenario 2 + 50% reduction in food loss (Scenario 2, 3 & 4 do not reduce fish)
Harris et al. (2017)	WF	Nation	India	-	-
Abeliotis et al. (2016)	GWP	Nation	Greece	-	-
van Dooren and Aiking (2016)	GWP & LU	Nation	Netherlands	31-50	*Reference:* Various references 1) Mediterranean Diet, 2) New Nordic Diet, 3) Low Lands Diet, 4) Optimized Low Lands Diet
Vanham et al. (2017)	WF	Nation	5 Nordic Countries	>2	*Reference:* Nordic Nutrition Recommendation 1) Healthy Omnivorous Diet, 2) Healthy Pescatarian Diet, 3) Healthy Vegetarian Diet
Hess (2015)	WF & Water scarcity footprint	Nation	UK	19 - 50	*Reference:* Eatwell Plate 5 Scenarios based on various ratios of 5 food groups: carbohydrates, protein, dairy, vegetable and fruits, food high in fats and sugar
Gill et al. (2015)	GWP, WF, LU, P & N use	Nation	Brazil, China & India	-	-
Conrad et al. (2018)	LU & WF	Nation	USA	>2	-
Yue et al. (2017)	GWP	Nation	China	-	*Reference:* Chinese Dietary Guideline 1) Recommended Diet
Eberle and Fels (2015)	GWP, EU,particulate matter, LU & WF	Nation	Germany	-	-
Salmoral and Yan (2018)	Energy, WF	Region	UK	-	-
Hallstrom et al. (2017)	GWP	Hypothetical	USA	-	*Reference:* USDA Food Pattern 1) reduction in red and processed meat,2) increase in fruits and vegetables, 3) increase in whole grains
Castane and Anton (2017)	GWP & LU	Hypothetical	Spain	adults	*Reference:* Spanish Mediterranean Diet and Vegan Society 1) Mediterranean Diet, 2) Vegan Diet
Camanzi et al. (2017)	GWP	Hypothetical	EU-27 countries	-	-
Van Mierlo (2018)	GWP, WF, LU & fossil fuel depletion	Hypothetical	Netherlands	-	*Reference:* - 1) Vegetarian Diet, 2) Vegan Diet, 3) Insect-Based Diet, 4) Fortification-Free Diet
Heller and Keoleian (2015)	GWP	Hypothetical	USA	-	*Reference:* USDA Food Pattern 1) Calorie-adjusted & Nutritionally-Balanced Diet
Downs and Fanzo (2015)	GWP, WF & Ecological footprint	-	-	-	*Reference:* Mozaffarian et al. 2011 Cardio-Vascular Prevention Diet

In these studies, the dietary patterns of individuals have been studied in one of two ways. In some studies, the diets are classified based on the presence or absence of meat or fish (e.g., omnivorous vs. vegetarian) as in Rosi et al. (2017). In contrast, instead of defining diets based on meat or fish consumption, some studies consider the amount of plant products individuals consume (i.e., high, medium or low plant-based diets), such as Biesbroek et al. (2018) and Lacour et al. (2018). Mainly, these studies understand the distribution of dietary patterns in studied population or how identified dietary patterns are changing over time.

1.3.2.1 Alternative Diets: Nutritionally-Balanced

A growing number of studies are beginning to understand what would have changed if the population that is studied switched to a nutritionally-balanced diet. Typically, these diets are modification of actual diets that are derived from identified dietary patterns. These healthy diets are formulated based on various sources and types of food consumed, such as: 1) dietary guideline recommendations, such as UK's Eatwell Plate by Hess et al. (2015) and Canada's Food Guide by Veeramani et al. (2017); 2) different types of dietary patterns based on animal-product content, such as Omnivorous and Vegetarian; 3) adjusting the amount of certain food products, such as animal, dairy and plant-based ones, as well as regional diets considered healthy, such as Mediterranean and Nordic.

Dietary guidelines and nutrition recommendations provide information on how to attain healthy diets by providing the types and amounts of food products to be consumed for different food groups by serving or plate sizes based on the main nutrients those food groups provide. Some studies use national dietary guidelines to assess the nutritional profile of diets analyzed (e.g., USA by Heller & Keoleian (2015) and Tom, Fischbeck, & Hendrickson (2016), Canada by Veeramani et al. (2017), China by Yue, Xu, Hillier, Cheng, & Pan (2017), Netherlands by van de Kamp et al. (2018), and UK by Hess et al. (2015). Others apply nutrition recommendations by Nordic Nutrition as in Röös, Karlsson, Witthöft, & Sundberg (2015), Seves et al. (2017) and Vanham (2016), basic dietary recommendations of WHO by Jalava et al. (2016) and FAO by Jalava et al. (2016). These guidelines and recommendations have differences on the amounts and types of foods they recommend for a healthy diet as these vary based on cultures, regions, and average body mass indexes of population studied. Others design healthy diets based on existing diets Pescatarian, Vegetarian, Lacto-ovo-vegetarian and Vegan. Those studies are Abeliotis et al. (2016), Pairotti et al. (2015), Tyszler, Kramer, & Blonk (2016) and Vanham (2016). Some studies focus on specific type of food products and reduce their amounts, such as meat and dairy products. Those studies are Abeliotis et al. (2016), Notarnicola, Tassielli, Renzulli, Castellani, & Sala

(2017), Seves et al. (2017), Song, Li, Fullana-i-Palmer, Williamson, & Wang (2017). When formulating nutritionally-balanced diets, referring to a nation's food guide can be more realistic as healthy food consumption education is provided through these sources as a guidance to attain healthy population.

1.3.3 Methods Used to Quantify Environmental Impacts of Food Consumption

In order to quantify environmental impacts of food consumption, various methods have been used, ranging from complex environmental and statistical analysis to simple calculations; however, all these methods follow a life cycle assessment approach. A summary of methodological decisions, as discussed below, are provided in Table 2 .

At a high level, the life cycle assessment approach assesses environmental impacts of products considering inputs and outputs throughout all stages of production from extraction to disposal (Rebitzer et al., 2004). Inputs are materials (e.g., fertilizer) and energy (e.g., electricity) and outputs are emissions (e.g., carbon dioxide (CO_2)) and waste (Rebitzer et al., 2004). As an example, the life cycle impacts of 1 kg of tomatoes at retail would be determined as follows: (1) quantify all the emissions indicators (e.g., CO_2, ammonia) at each stage of the life cycle (tomato production, transportation, packaging, storage); (2) assign each indicator to an impact category (e.g., CO_2 to global warming potential, ammonia to acidification and smog); (3) multiply the indicators by a characterization factor, to quantify how each emission indicator contributes to environmental impacts, such as global warming potential; (4) sum up all impacts. Specifically, for global warming potential (GWP) characterization factors are expressed in kg CO_2 equivalence (kg CO_2 eq.). If the production of 1 kg of tomato emits 0.5 kg of carbon dioxide (CO_2) and 0.5 kg of methane (CH_4), and the GWP is 1 kg CO_2 eq. for CO_2 and 28 kg CO_2 eq. for CH_4, then 1 kg of this food product would contribute 14.5 kg CO_2 eq. to GWP and 10 kg of the same food product would contribute 145 kg CO_2 eq. to GWP.

Most diet-related studies that consider environmental impacts of food consumption use some type of life cycle approach, specifically: (1) life cycle assessment (LCA), (2) LCA with economic input-output analysis (LCA-eIOA), (3) basic life cycle thinking (LCT), and (4) LCT with linear programming. Specifically, there is no difference between LCA and the other three methods in terms of how environmental impacts of food products are quantified, but there are differences in terms of how these impacts are interpreted, as discussed next.

LCA has certain characteristics that makes it the most comprehensive method among the other three methods discussed here for quantifying environmental impacts. Mainly, LCA studies can follow a standardized method by International Organization for Standardization (ISO) that ensures consistency among studies (ISO, 2006b, 2006a). In order to provide consistency, ISO requires several rules to be applied that are as follows: (1) determine function of a product, (2) define system boundaries, and (3) determine impacts to be assessed (as explained in the following sections). Typically, LCA is conducted by using specific software tools and databases that compile data and perform complex calculations. Examples of commonly used software tools are SimaPro, OpenLCA, and Umberto. When using databases, LCA includes a data quality matrix to acknowledge the issues associated with data used. The reason is that this is one of the main improvement areas of LCA studies, which will be explained in Section 1.3.4.3. The unique and important characteristics of LCA over other methods is that LCA allows to identify stages, i.e., hotspots, where the highest environmental impacts occur along the entire life cycle stages of a product, a food consumed or entire diet. Once these hotspots are identified, then improvement strategies specific to those hotspots can be considered to reduce the related impacts.

One of the other methods used is LCA – eIOA, which is a hybrid method that is composed of monetary values and environmental impacts of several economic sectors, not individual products (Matthews & Small, 2000). At a high level, this method is a simple tool that quantifies total amount of products produced in major economic sectors and multiplies this absolute amount with average impacts of 1 kg of products included in analyzed sector to quantify total impacts for that sector. Then, it calculates the economic value with the same approach (Carnegie-Melon University, n.d.). This would give, for example, the total cumulative CF and economic value of USA milk sector for only production. Studies that investigate economic values and environmental impacts at national scale prefer this method. To be more specific, Hallström et al. (2017) quantifies potential cost improvements of CF and health system gained from attaining a healthier diet by using LCA – eIOA. Other studies focus potential monetary improvements and environmental impacts are Goldstein, Moses, Sammons, & Birkved (2017), Pairotti et al. (2015), and Yue et al. (2017). Unlike LCA, this method cannot identify hotspots of impacts. Consequently, this method cannot inform policy-makers about the important stages to be focused to improve costs and reduce impacts.

LCT is a common practice mainly among nutrition researchers who are interested in understanding the link between robust nutrition assessment of diets and associated environmental impacts. Mainly, these researchers try to answer how they can shift consumers' dietary patterns towards healthier and low environmental resource-intensive ones simultaneously. To do this, these studies take three broad steps: (1) analyze demographic characteristics of consumers to provide insights for new strategies to target specific groups of society; (2) assess the nutrition profile of food consumed, by analyzing various macronutrients and micronutrients; (3) assess environmental impacts of food consumption of their target group typically using data from previous LCA studies or existing LCA databases.

Mainly there are two LCT methods used, which is basic LCT and LCT with linear programming. Basic LCT assesses impacts of diets using simple calculations, determining environmental impacts of a diet by multiplying average amounts of food products with their associated impact values obtained through LCA studies and databases. Studies that use basic LCT are mainly interested in improving nutritional profile of diets and understanding the impacts. Instead, LCT with linear programming can answer more complex questions, such as finding the optimum diet that minimizes environmental aspects and at the same time maximizes nutritional assessment (van Dooren & Aiking, 2016). Criteria for optimizing outcomes are input to a software as constraints and the software solves these constraints using a computational technique known as linear programming. Van Dooren and Aiking (2016) illustrated that by using this method, any optimal diet that is environmentally-friendly and nutritionally-balanced can be determined. Many of the recent studies prefer this method to find optimum dietary intakes that are environmentally-friendly.

Besides these benefits, LCT methods have some shortcomings compared to LCA when assessing environmental impacts. First, LCT methods do not always follow ISO standardization that constrains the accuracy of impact results. Second, LCT obtains impact data from LCA studies and databases for an entire system boundary instead of doing a stage-by-stage analysis. Consequently, this shows aggregate environmental impacts and not the hotspots stages. So, for example, LCT methods cannot tell whether hotspots of diets shifted from retail sector to production or to cooking, limiting the information it can provide to policy-makers, food sector specialists, researchers and consumers.

1.3.4 Quantifying Environmental Impacts of Food Consumption

As discussed in previous section, LCA is the main method used to quantify environmental impacts of consumed foods. However, several methodological inconsistencies exist in conducting LCA. The main inconsistencies appear in the system boundaries assessed, life cycle inventories used and functional units determined.

1.3.4.1 System Boundaries Assessed

In LCA studies, the system boundary shows the stages of a product that are considered in the analysis of the product's life cycle. Defining the systems boundary appropriately is very important as it shows exactly which stages' emissions and waste are taken into account in the assessment. The determined boundary directly affects the results of environmental impacts. Examples of various stages in food LCA studies can be production at farm, processing, retail, consumption, transportation, storage, cooking, and disposal of consumed and wasted food.

In order to assess the environmental impacts of a diet comprehensively, it is important to account for all stages from production to disposal (Notarnicola, Sala, et al., 2017). This is because for different products, the hotspots might occur at different stages of a life cycle. For example, the hotspot stage of beef products is the production and not at transportation or retail. In contrast, the hotspot stage of locally-sourced fruits might be the production, whereas the hotspot stage of imported-fruits from long distances might be the transportation. Thus, in diet-related environmental studies, it is not only important to understand the amounts and types of food consumed, but also to identify system boundaries and associated stages in order to have robust results.

Table 2 shows the recent studies on the environmental impacts of diets and the different system boundaries they consider. Example boundaries in the tables are production, production to consumption, production to retail, and production to distributor. The system boundary a study chooses is based broadly on the research question of the study. Specifically, the impacts the research question assesses and the production systems and diets it compares determine the system boundary of the study.

Typically, studies interested in quantifying CF define system boundaries of impacts from production to consumption. This is because food products can have different CF contribution along the different stages of the supply chain. Researchers can also sometimes focus only on some stages if this is more appropriate for their research questions. For example, Treu et al. (2017) was interested in understanding CF of conventional and organic food consumption, so they focused on stages where there might be significant difference in CF between two different production systems, such as production and retail, and excluded the other stages. Similarly, van Dooren & Aiking (2016) analyzed different diets to find the diet with minimum CF and included only cooking stage and excluded shopping trip and storage stages, of which the CFs are not affected by different types and amounts of food consumed. However, it is worth noting that sometimes studies with similar research questions do not choose the same stages within the same system boundaries.

Table 2. Summary of reviewed dietary patterns studies since 2015 ordered by methodological approach

Reference	Methods Quantify Impacts	System Boundaries	Functional Unit	Nutritional Indicator	Life Cycle Inventory Data Source	Data Collection for Food Consumption	Food Loss
Salmoral and Yan (2018)	LCA	production	Calories	-	Agri-footprint	National Survey	-
Treu et al. (2017)	LCA	production	Mass	-	Literature LCA studies	24-hr recall & 4 weeks history interview	*Reference:* Meier & Christen coefficients production
Notarnicola et al. (2017)	LCA	production to consumption	Mass	-	Agri-footprint & Ecoivent	FAO Food Balance Sheet	*Reference:* Gustavson 2011 production, storage, packaging & distribution
Eberle and Fels (2015)	LCA	production to consumption	Mass	-	Gemis 4.81 & Ecoinvent 3.01	National Statistics	*Reference:* Gustavson et al. 2011, Kranert et al. 2012 & Peter et al. 2013 production, post-harvest, processing, distribution & household
Castane and Anton (2017)	LCA	production to consumption	Calories	Nutrient Rich Food Index	Literature LCA studies & Ecoinvent	Hypothetical	-
Hallstrom et al. (2017)	LCA-eIOA	production to retail	-	-	Literature LCA studies	Hypothetical	*Reference:* USDA LAFA processing & retail
Pairotti et al. (2015)	LCA-eIOA	production to consumption	Mass	-	National price data	National Statistics	-
Goldstein et al. (2017)	LCA-eIOA	production	-	-	Water Footprint Network Ecoinvent	Hypothetical	*Reference:* USDA LAFA retail & household
Yue et al. (2017)	LCA-eIOA	production	Calories & Protein	Chinese Dietary Recommendation	Finkbeiner, 2009	National Statistics	-
Camanzi et al. (2017)	LCA-eIOA	-	-	-	National price data	Hypothetical	-
Harris et al. (2017)	Basic LCT	production	Calories	-	Water Footprint Network	24-hr recall	-
Temme et al. (2015)	Basic LCT	production to consumption	Calories	-	Ecoinvent	24-hr recall	-
Tom et al. (2016)	Basic LCT	production to consumption	Calories	USA Dietary Recommendation	Water Footprint Network LCA Studies Heller and Keoleian, 2014	24-hr recall	*Reference:* USDA LAFA retail & household
Milner et. al. (2015)	Basic LCT	-	Calories & Mass	-	LCA Studies	Self-recorded diary	*Reference:* USDA LAFA production, retail and household
Vazquez-Rowe et al. (2017)	Basic LCT	production to distribution	Calories	-	LCA Studies & Ecoinvent v3.2	24-hr recall	*Reference:* Gustavson et al. 2011 production, storage, packaging & distribution

Reference	Methods Quantify Impacts	System Boundaries	Functional Unit	Nutritional Indicator	Life Cycle Inventory Data Source	Data Collection for Food Consumption	Food Loss
Heller et al. (2018)	Basic LCT	production to processing	Calories	-	LCA Studies	24-hr recall	*Reference:* USDA LAFA retail & household
Rosi et al. (2017)	Basic LCT	-	Calories	Italian Mediterranean index	Barilla Center	Self-recorded diary	-
Hyland et al. (2017)	Basic LCT	production to consumption	Calories	-	LCA studies	National Survey	*Reference:* USDA LAFA only after consumption at household
Walker et al. (2018)	Basic LCT	-	-	Nutrient Rich Food Index	ZHAW & Ecoinvent	FFQ	*Reference:* Beretta 2017 food supply chain
Roos et al. (2015)	Basic LCT	production to consumption	Calories	Nordic Nutrient Recommendation	LCA studies	National Survey	-
Jalava et al. (2016)	Basic LCT	production	Calories	WHO & FAO recommendations	Water Footprint Network	FAO FBS	*Reference:* Gustavson 2011 & Parfitt 2010 production, post-harvest, processing, distribution & household
Vanham et al. (2017)	Basic LCT	production	Calories & Protein	Nordic Nutrition Recommendation	Water Footprint Network	FAO FBS	*Reference:* Vanham et al. 2015 household & restaurant
Hess (2015)	Basic LCT	production to consumption	-	Eat Well Plate Score	Water Footprint Network & Water Scarcity	National Statistics	*Reference:* National Trade Data food supply chain
Downs and Fanzo (2015)	Basic LCT	production to consumption	-	Cardio-protective diet	Barilla Database Water Footprint Network	Health Study	-
Gill et al. (2015)	Basic LCT	production	Calories & Protein	-	Faostat Water Footprint Network	FAO FBS	-
Conrad et al. (2018)	Basic LCT	production and consumption	Calories	Healthy Eating Index	USA Footprint	24-hr recall	*Reference:* USDA LAFA household
Heller and Keoleian (2015)	Basic LCT	-	Calories	USA Dietary Recommendation	LCA studies	Hypothetical	*Reference:* USDA LAFA retail & household
Marije Seves et al. (2017)	Basic LCT	-	-	Nordic Nutrition Recommendation	Agri-footprint	24-hr recall	-
De Laurentiis et al. (2017)	Basic LCT	-	Mass	-	LCA studies Water Footprint Network	Self-recorded inventory	*Reference:* De Laurentilis 2016 production, retail & household
Blas et al. (2018)	Basic LCT	production	Mass	-	Water Footprint Network	Self-recorded diary	*Reference:* "More Food, Less Waste" production, retail & household
Song et al. (2017)	Basic LCT	-	-	Chinese Nutrition Society: macronutrients	Barilla Center	National Survey	-

Reference	Methods Quantify Impacts	System Boundaries	Functional Unit	Nutritional Indicator	Life Cycle Inventory Data Source	Data Collection for Food Consumption	Food Loss
Abeliotis et al. (2016)	Basic LCT	production	-	-	Barilla Center	FAO FBS	-
Van Mierlo (2018)	LCT - Linear Programming	production	-	USA Recommendations	LCA studies	Hypothetical	-
Kramer et al. (2017)	LCT - Linear Programming	-	-	Dutch Food Composition: all nutrients	Agri-footprint & LCA studies	24-hr recall	*Reference:* Van Westerhoven and Steenhuizen2010 household
Biesborek et al. (2018)	LCT - Linear Programming	production to consumption	Calories	Dutch Healthy Diet Index	Agri-footprint	FFQ	*Reference:* - production, retail, transportation & consumption
Fresan et al. (2018)	LCT - Linear Programming	production to processing	Mass	Mediterranean Diet index	LCA studies	FFQ	-
Lacour et al. (2018)	LCT - Linear Programming	production	Calories	Adequate Nutrient Intake Score	Dialecte	FFQ	-
van deKamp et al. (2017)	LCT - Linear Programming	production to consumption	Calories	Wheel of Five Score	Agri-footprint	National Survey	-
Perignon et al. (2016)	LCT - Linear Programming	-	-	Mean Adequacy Ratio	National price data	Self-recorded diary	-
van Dooren and Aiking (2016)	LCT - Linear Programming	production to consumption	Mass	Health Score: 10 nutrients	Agri-footprint	Cultural research	-
Tyszler et al. (2016)	LCT - Linear Programming	production to consumption	-	Dutch Food Composition	Agri-footprint	24-hr recall	*Reference:* Van Westerhoven and Steenhuizen 2010 household
Ribal et al. (2016)	LCT - Linear Programming	production to consumption	Mass	-	LCA studies	Hypothetical	-

1.3.4.2 Functional Unit: Comparing diets

In LCA studies, the function of the system needs to be defined so that products can be compared. The function refers to the primary function of product studied (Rebitzer et al., 2004). This primary function is represented in quantities to define its functional unit in numbers. The functional unit (FU) acts as a bridge between the function of a product and a reference measurement of the system (Matthews, Hendrickson & Matthews, 2015) and enables to compare different systems studied. The reference measurement (i.e., reference flow) is the amount of product that needs to be bought, used or consumed to fulfill the function of the system. As an example, the primary function of food is to provide energy, and its *FU* could be determined as 2000 calories per person per day. The reference flow would then be the amount of each type of food that is required to provide 2000 calories.

Currently, within the LCA community studying food-related topics, there is no consensus on the primary function of food consumption. There are various suggestions for defining a diet's primary function, such as providing energy, protein and nutrition, and secondary functions, such as pleasure, social interaction, and culture (Heller, Keoleian & Willett, 2013). However, in LCA studies, it is difficult to capture secondary functions, as these can be difficult to quantify. Prior studies have focused on the primary function of food consumption and used different functional units, such as mass, calories, and protein as presented in Table 2. Among these functional units, calorie-based FU is the most commonly used. The main shortcoming of calorie-based functional unit is that it cannot capture important functions of different types of food products. For example, the primary function of grains is to provide complex carbohydrates for energy, whereas meat products primarily provide protein, and vegetables primarily provide micronutrients.

The functional unit can also have a time aspect. For example, calories can be based on daily, weekly, monthly or yearly intakes. Many studies prefer to analyze at daily and yearly, such as Lacour et al. (2018), Röös et al. (2015), van de Kamp et al. (2018), and Vázquez-Rowe et al. (2017). Few studies focus on weekly or monthly food consumption, such as Castañé & Antón (2017). In terms of scale, the FU can be further defined at the individual, household or national level. Many researchers study average individual food consumption. Only Pairotti et al. (2015) focuses on household average.

Considering the wide range of primary functions of different types of food products, and also their biological interactions based on different combinations within diets (Sonesson, Davis, Flysjö, Gustavsson, & Witthöft, 2017), makes defining FU even more complex. In LCA studies, identifying and calculating primary FU of food consumption still continues to the area to be developed.

1.3.4.2.1 Incorporating Nutrition into FU

More recently some researchers, Castañé & Antón (2017) have used nutrient-related FU based on nutrient density including macronutrients and micronutrients. The use of nutrition-based functional units are becoming more popular as these can show total function of a food product that is represented by index scores that considers various macronutrients and micronutrients.

Within environment-related dietary pattern studies, the main nutritional indicators preferred to assess quality of dietary patterns are *nutrition quality index scores*, *dietary guidelines* and *nutrition recommendations*. Nutritional quality index score gives a score within a range, e.g., 0 – 10, to show the ratio of nutrients versus calories obtained from that specific food product. These scores are added up to give the nutritional quality index of a diet.

Mostly nutritional quality index scores are preferred to evaluate the nutritional quality of consumed food. In the last years, among public health researchers, there is a trend towards shifting to healthy diets that consist of high amount of vegetables, fruits, unrefined cereals, legumes as protein resource and non-saturated fats (Harvard Medical Health, 2014; Harvard School of Public Health, 2014). Subsequently, Mediterranean diet provides main characteristics of this healthy diet and its quality index is named as MedIndex by Fresán et al. (2018), Pairotti et al. (2015), and Rosi et al. (2017) being the most commonly referred one. The other indexes used are typically depends on the origins of population. These indexes are Dutch Healthy Diet Index by Biesbroek et al. (2018), PanDiet Index by Lacour et al. (2018), Nutrient Rich Food Index by Castañé & Antón (2017) and Walker et al. (2018), Healthy Eating Index by Conrad et al. (2018), relative risk for non-communicable disease (NCD) index by Hallström et al. (2017). Current index scores do not perform as FU, because different dietary patterns assessed in the same study result having different scores, instead of having the same FU among all diets analyzed.

1.3.4.3 Life Cycle Inventories

A key activity in LCA studies is developing the life cycle inventory (LCI). *LCI* is composed of gathering data on all inputs and outputs associated with a product system along all its production stages within the defined system boundary (Rebitzer et al., 2004). There are two main LCI activities: (1) background data; and (2) foreground data (Bo P. Weidema, 1998). Background data is compiled based on mainly reports and scientific studies that provide information on how much input (i.e., raw materials, manufactured materials, energy, etc.) and output (i.e., wastes, by products and emissions to air, soil, and water) are used to produce one unit of a product. These data form LCA databases that can be used to build models and save time in collecting data for common inputs needed in product systems. Table 2 shows some examples of existing databases, such as Ecoinvent, Barilla, Agri-footprint, Gemis and ZHAW. These databases typically include the LCI for the production of various materials (e.g., wood, plastic, fuels, fertilizers), transportation modes, electricity and fuel combustion, and manufacturing processes.

In contrast, foreground data includes any user-generated data for the specific system studies (Bo P. Weidema, 1998; Bo Pedersen Weidema & Wesnæs, 1996). An example would be the average amount of food products consumed in a day. This user-generated data can also include data for some food products that are sourced from areas without background data, or for which the background data is for a region other than the one studied. Suppose a researcher is studying Canadian tomato production but only has background data for tomato production in Mexico. Then the researcher could develop foreground data to represent Canadian climate and agricultural practices. For example, the researcher can adjust the amount of fertilizers and pesticides in the background data according to Canadian yields.

It is important to develop sound foreground data for food products, but it is very challenging due to complex systems of agricultural activities that vary from region to region. Specifically, regional management practices, such as organic and conventional, and agronomic characteristics, i.e., local fertility and dryness levels of soil and local climate conditions, affect the amount of inputs and outputs considered in the product system. Because of those variations, different regions use different amounts of fertilizer, pesticide, water, agricultural machinery, and other resources to produce the same amount of a certain type of food product. These several variations in agricultural production make it difficult to develop regionalized databases for all agricultural regions in various countries. Current existing databases are mainly developed for European agriculture systems for various food products. In contrast, Canadian databases are very limited in terms of different types of food products analyzed and are still under development. For example, garlic, a commonly consumed spice, does not exist in any of the Canadian existing databases.

Besides all challenges due to complex agricultural systems, it is important to use high quality databases (Weidema & Wesnæs, 1996) that include information that is consistent with existing agricultural management systems, and reflects agronomic conditions. Typically, it is suggested to benefit from databases developed based on ISO standards and reviewed by LCA specialists (ISO, 2006b, 2006a); although several studies do not follow this suggestion e.g., van de Kamp et al. (2018).

1.3.4.3.1 LCI Data Collection for Food Consumption

In diet-related studies, collecting foreground LCI data for food consumption is very fundamental. Researchers who are interested in analyzing the impacts of food consumption typically focus on daily food consumption, instead of focusing on meals (Heller, Keoleian, & Willett, 2013). Meals provide information on types of food consumed, but does not necessarily show total daily food intake. Specifically, this limits the understanding of eating habits throughout a day and obtained total nutrients that can be compared with daily recommendation intakes provided by health and nutrition specialists. Daily food consumption information can be gained from variety of food consumption data available. The main data sources used in prior work are shown in Table 2 and are as follows:

(1) *Food balance sheets* (FBS): *FBS* provides information on a nation's food supply trade only for human consumption for a specific time period by compiling the quantity of food stocks, production, imports and exports. This aggregated data also includes food waste occurring at all stages of the food supply chain and does not provide information on what has been consumed by individuals excluding waste amounts. Mainly there are two sources of FBS: (1) FAO FBS; and (2) national FBS, such as in UK, Italy, Sweden and China.

From this compiled data, one can analyze per capita average food consumption of a nation. However, FBS cannot give information about preferences of individuals or groups of individuals in a population. For example, from this data, it is not possible to understand the environmental impacts of omnivorous and vegetarians of a population. Instead, the studies using FBS focus on quantifying environmental impacts, of average or total food consumption at global, continental or national level. Studies use FBS provide aggregate information about the total CF or WF of a country, region, or a city, due to food consumption, and broadly study which food products at an aggregate level have how much environmental impacts. However, they do not identify the share of each dietary group in the studied populations in the total footprints.

In addition, FBS data can also provide information on the origins of imported food products. This is important as a country that imports some of its products from another country can have important environmental burdens at the exporting country. Specifically, environmental impacts, such as CF due to transportation, WF or land use (LU) due to production can cause significant impacts in other countries. Examples of studies that used FBS data to identify the origins of imported food products to quantify CF associated with transportation are Jalava et al. (2016), Notarnicola, Tassielli, et al. (2017), Pairotti et al. (2015), and Yue et al. (2017) as shown in Table 2.

(2) *Self-reported surveys* (SRS): *SRS* collect information on food consumed by participants. Unlike FBS, SRSs gives information at individual level that can be analyzed to understand eating patterns and components of consumption of individual food products of different groups of population. By analyzing these surveys, the share of various eating habits, or nutritional assessment of food consumption of a population can be assessed. These surveys are conducted by 3 different methods: 24-hr recall interviews, food frequency questionnaires (FFQ) or self-recorded diaries.

24-hr recall interviews gather information on daily food consumption of participants about the previous day or days. Typically, these interviews are conducted at a couple of stages and at a detailed level to lower the probability of forgotten food products. The 24-hr recall interviews can focus on 1 day, or 2 days, or 4 days. For example, Heller, Willits-Smith, Meyer, Keoleian, & Rose (2018) quantified CF and energy use of average USA food consumption by analyzing quintiles mean based on individual 24-hr recall. However, 24-hr recall interviews cannot demonstrate individuals' day to day food consumption variations, specifically food types and amounts, as this method typically focuses on one or few days of consumption. For example, a participant can consume only plant-based products on the day of interview, and identified as vegetarian, however, this participant might be consuming animal-based products on the other days. Even considering this shortcoming, this survey method provides a good understanding of eating habits of a population when large number of participants are assessed.

Researchers interested specifically in organic food consumption used slightly different survey methods. Lacour et al. (2018) and Treu et al. (2017) aim to understand environmental impacts of conventional and organic diets. Lacour et al. (2018) analyzed a FFQ on organic food products that gathered information on consumers' consumption of organic foods. In contrast, Treu et al. (2017) used a hybrid method by combining 24-hr recall interviews with diet-history interviews where participants report what they have eaten in the past month during personal interviews. Different from 24-hr recall interviews, diet-history interviews gather information more on consumers' purchasing behavior, specifically conventional or organic products.

FFQs provide a list of food items and asks the consumption frequency and size over past day, month, or year. These studies are Biesbroek et al. (2018), Fresán, Martínez-Gonzalez, Sabaté, & Bes-Rastrollo (2018), and Walker, Gibney, & Hellweg (2018). As FFQ can gather information not only for the previous day, but also for the previous month, there is a possibility that participants might forget some of the food products consumed (Kirkpatrick et al., 2014). In order to test the accuracy of FFQs, Biesbroek et al. (2018), after conducting FFQ, applied 24-hr recall interviews followed by urine and blood test to examine the accuracy of responses reported in the FFQ.

Self-recorded diaries collect information on food consumed by participants' own records for several consecutive days, such as 4 days by Milner et al. (2015) or a week by Perignon et al. (2016) and Rosi et al. (2017). Before starting to record, participants get training on how to record the ingredients, the amounts and sizes of the food as well as other information, such as the meal in which the food is consumed. Similar to 24-hr recall interviews, self-recorded dairies can fall short in determining food consumption variations depending on the length of study. If the study is conducted for a week, then it should capture variations more accurately compared to 4 days. In addition, participants can change their eating behaviour unintentionally that would result in showing untypical food consumption (Kirkpatrick et al., 2014).

Although each survey method has its own shortcoming, 24-hr recall interviews reveal more accurate information over the other methods (Kirkpatrick et al., 2014). Main advantages of 24-hr recall interviews can be grouped into two categories: nutritional daily intake and being more realistic. Specifically, this method assesses nutritional daily intake, such as energy and protein, more accurately than the other self-reported surveys. This is evidenced by studies that performed a blood test to evaluate accuracy of survey methods. Even though, 24-hr recall interviews have higher accuracy over other survey methods, it should be noted that none of the SRS are ideal to calculate particularly absolute energy intakes of individuals (Kirkpatrick et al., 2017). Moreover, unlike FFQs, 24-hr recall interviews do not limit that participants choose from a list of consumed food products that might limit assessment of nutritional intake. Finally, unlike in food diaries, 24-hr recall interviews do not have a possibility of participants changing food consumption behaviour as it is conducted for previous consumption day.

Diet-related studies, not only analyze actual food consumption, but also hypothetical diets. These hypothetical scenarios are based on various diets, such as Mediterranean and Vegan diets by Castañé & Antón (2017), Insect-based diet by Van Mierlo, Rohmer, & Gerdessen (2017), Fortification-free diet by Van Mierlo et al. (2017) and Cardio-protective diet by Downs & Fanzo (2015), dietary guidelines by Heller & Keoleian (2015).

1.3.4.3.2 Adjusting Food Amounts Due to Food Loss

An important part of developing the LCI for food studies is accounting for waste. Almost one third of world's produced food is estimated to be lost along food supply chain, including in production, transportation, processing, retail, and before and after consumption (Gustavsson, Cederberg, & Sonesson, 2011). Thus, total lost food contributes to the amount of food consumed in diets. For example, in total 68% weight of oranges produced are lost in the processing, retail, and household stages (USDA, 2018a). Specifically, the main food lost occurs at consumer level, except for meat products where the main loss happens during production while converting from live weight to boneless meat. In that process, approximately 60% of a live weight is lost to obtain edible portion (i.e., boneless meat) (Nold, 2013). Therefore, in order to assess environmental impact of diets more accurately, food loss needs to be accounted for all stages included along food supply chain (Corrado et. al., 2017).

Inconsistencies of food loss among studies are presented in Table 2. Some studies do not consider food loss at all. Some studies consider food loss at different stages, such as only at production, at retail or at consumer level. This brings a limitation when comparing studies, because food loss can have significant impacts depending on the total amount lost (Notarnicola, Sala, et al., 2017).

There exists several food loss sources. Many studies refer to USDA Loss Adjusted Food Availability (LAFA) (USDA, 2018a) and FAO global food waste report (Gustavsson et al., 2011). Both food loss sources are based on estimations looking at the trade statistics and interviews conducted with stakeholders involved. However, not all studies have the same origins with the food loss sources, which might bring inaccuracy when accounting food loss. In order to avoid this inaccuracy, several studies used prior food loss work from the same country studied where possible, such as Germany by Kranert et al. (2007) and Peter et al. (2013), Spain by Ministerio de Agricultura Alimentación y Medio Ambiente (2015), Switzerland by Beretta, Stucki, & Hellweg (2017), and Netherlands Van Westerhoven & Steenhuizen (2010).

1.3.5 Environmental Impacts Assessed

As explained in Section 1.3.4.3, in diet-related LCA studies, environmental impacts that can be assessed directly depend on the availability of two pieces of data in LCI databases. First, data on the indicators of the impact might be missing. For example, one may not be able to study the biodiversity loss impact of food production for some regions, because there is no information on the land use indicator of food products in LCI databases. Second, data on indicators might be available but there may not be data on the regional characterizations factors of the indicators. For example, it may not be possible to study WF of food products effectively because although there may be data on the water use of food products, the regional water scarcity factor of the used water may not exist. Often, the impacts commonly assessed are the ones that are calculated with a global characterization factor, such as CF and energy used, which do not require detailed regional environmental information. Table 2 shows the prior studies and the impact factors they study. The only study that assesses an impact other than CF and energy use is Hess et al. (2015), which calculates WF based on regionalized characterization factor through water scarcity index developed by Pfister, Koehler, & Hellweg (2009). This scarcity index is a quantitative assessment of vulnerability of water resources to water scarcity. Other studies that quantify WF use a different method developed by (Mekonnen & Hoekstra, 2011) that aggregates total amount of water used to produce a food product. The main difference between these two WF methods is that the former one assesses impacts on the environment, whereas the latter one sums total amount of water used without considering regional characteristics. Finally, Röös et al. (2015) used FAOSTAT data to quantify changes due to agricultural activities for assessing LU, but this cannot be considered an impact assessment.

Agricultural activities driven by food consumption have significant direct and indirect impacts on the environment, which is not limited only to climate change. Global agricultural pressure on available fresh water resources and land use change are respectively estimated to be 70% (FAO, 2016; OECD, 2016) and 30% (Ramankutty et al., 2018). These intensive resource uses contribute to other environmental impacts, such as eutrophication (EU), acidification (AC) and biodiversity loss. All of these impacts are interlinked, but the lack of LCI data limits the impacts that can be assessed other than CF. Other impacts can only be studied for some regions where LCI data is available. One such study is Notarnicola, Sala, et al. (2017), which calculated 14 different impacts of Europeans' food consumption. It is important to expand this LCI data to other regions of world in order to assess environmental impacts of food consumption comprehensively.

Comprehensive quantification of environmental impacts of food consumption is important to understand the trade-offs between different food products. This is because some food products might be resource-intensive, others only carbon-intensive, and yet others only water intensive. For example, beef is a resource-intensive product and has high CF and WF, whereas vegetables have low CF, but can have high WF. If these trade-offs cannot be understood comprehensively, then pressures on environment might decrease for one perspective, such as climate change, but increase for another, such as freshwater use. As planetary boundaries show the importance of lowering pressures on all impacts (Steffen et al., 2015), it is important to understand these trade-offs in order to make sustainable food choices. Once trade-offs between different impacts can be assessed, it might be possible to inform policy makers, nutritionists and consumers about how to achieve sustainable food consumption.

Changes in food consumption patterns can have positive or negative impacts on the environment. Understanding the changes of environmental impacts of food consumption over longer time periods, say more than five years, is very important. This can give information to policy-makers and health specialists about changes in food consumption habits, and their associated impacts.

However, prior studies focus on a specific year and assess the environmental impacts associated with dietary patterns of that particular year. Yet the changes of environmental impacts of dietary patterns over the years have not been studied. Only Gill et al. (2015) analyzed the trends of food consumption at individual level per year from 1996 to 2011 and quantified the environmental impacts of food products that had significant changes in the last decade, but did not quantify the total food consumption nor assess impact trends of food consumption.

1.3.6 Summary of Literature and Research Implications

Review of diet-related environmental studies published in the last years shows that the nature of studies and methods used to identify dietary patterns, to assess health and to quantify environmental assessments are changing. There are several areas that require more work.

Functional units do no not capture the complexity of the function of diets. From health perspective, the main function of diets can be defined as providing energy and nutrition to the body. Many prior studies focus on energy and use calorie-based functional unit. This results in ignoring the other nutrients, which are essential, such as amino acids, vitamin B_{12}, and other micronutrients. Prior studies investigate nutritional quality and environmental impacts of food consumption from various sources. This shows that there is a need in finding a nutrition-related FU. In recent years, there have been some attempts to determine nutrition-related FUs by LCA practitioners Sonesson et al. (2017) and Stylianou et al. (2016). However, this is a new area of research that still requires development. Specifically, these nutritional index scores are relatively new to the LCA community and there is still no consensus on the best method to adopt.

LCI databases are limited for agricultural products in general, specifically in Canada. This lack of data availability affects assessment of environmental impacts of food consumption. Existing databases allow mainly CF assessment for various places. Due to this, in Canada, only CF of dietary patterns can be assessed. New database developments, that can assess all environmental impacts, is an urgent need, specifically in Canada. Once the data is available, it is important to quantify impacts of food consumption over a certain period of time longer than 5 years to understand changes in food consumption and their impacts.

These methodological issues are beyond the scope of this thesis. However, this thesis addresses an important knowledge gap in diet and environmental impact research. Specifically, it is important to understand temporal shifts in dietary patterns and their associated environmental impacts. This type of analysis can provide information on changes in dietary patterns, nutritional status assessment, food consumption, and their associated environmental impacts. Further analysis, linking changes to socio-demographic factors, economic changes, or cultural trends could provide useful insights for decision-makers, and nutritionists to find new policies and strategies to reduce environmental impacts, while improving health, but is not considered in this thesis. Results of such research also could be useful to increase awareness of targeted consumers about how changes in their food choices can affect their and environment's health.

Chapter 2 Methodology

The overall approach was to determine dietary patterns and to quantify carbon footprint (CF) of food consumption in Ontario. At a high level, methodology can be divided into two parts. In the first part, the Canadian Community Health Survey-Nutrition (CCHSN), which is a national survey conducted in 2004 and 2015, is analyzed to calculate food consumption and identify dietary patterns. In the second part, Life Cycle Assessment (LCA), which is a tool to quantify environmental impacts of products with life cycle methodology, used the results from first part to quantify CF of dietary patterns. CCHSN related sections are presented as follows: Section 2.1, 2.2 and 2.3. LCA methodology can be found in Section 2.4.

2.1 Canadian Community Health Survey – Nutrition

Statistics Canada, Health Canada and the Canadian Institute for Health Information have been conducting a series of surveys called the *Canadian Community Health Surveys* since 2000. These surveys gather information on the health status of Canadians and on how the overall health care system performs. Within these surveys, the *Canadian Community Health Survey-Nutrition* (CCHSN) surveys were designed to provide information on dietary intake and nutritional well-being of Canadians to inform and guide federal and provincial policy makers about food consumption, dietary patterns, nutritional and health status for evaluating food and nutritional security. This study uses the food consumption and nutrition data from CCHSN 2004 and 2015 (Health Canada, 2017; Statistics Canada, 2008, 2017a). The official titles of these surveys are the *2004 Canadian Community Health Survey Cycle 2.2-Nutrition* (2004 CCHS Nutrition) and the *2015 Canadian Community Health Survey-Nutrition* (2015 CCHS Nutrition). These are the most comprehensive and recent nutrition surveys available for people in Canada.

2.1.1 CCHSN's Participant Selection Criteria

The CCHSN is a nationally representative survey in that the participants cover people residing in private dwellings across the 10 Canadian provinces. The survey defines a set of predefined age-sex groups, such as below 4-to-8-female-male or 14-to-18-female or 14-to-18-male. Statistics Canada ensures that there are at least 80 participants recruited for each group from each province. In addition to these participants for each group, Statistics Canada recruits additional participants from each province in proportion to the provinces' populations. For example, approximately 10 times more participants are recruited from Ontario than in Manitoba because Ontario's population is approximately 10 times higher than Manitoba's.

Although the 2004 and 2015 surveys both use the above recruitment process, there are also two main differences between the participants recruited by these surveys:

i. *Number of Participants:* 2004 CCHS Nutrition recruited 35,107 participants that represent around 98% of the Canadian population, whereas 2015 survey recruited 20,487 participants that represent around 90% of the Canadian population. The 2004 survey has more participants mainly because Ontario, Manitoba, and Prince Edward Island provided extra funds for the survey in order to increase sample size and gain a better understanding of their populations. For example, Government of Ontario added 4,360 more participants to its initial sample population.

ii. *Age Groups:* In the 2004 survey, participants include all age groups, including ages below 1, thus breastfed respondents are represented in the survey. However, later Statistics Canada found that quantifying amount of breastmilk consumption is difficult. In 2015, Statistics Canada decided to exclude participants who primarily consume breastmilk, which was done by excluding participants younger than 1 year old.

2.1.2 Format of CCHSN

Statistics Canada surveys the participants by random sampling on different days of the year and asks two groups of questions: (i) the socio-demographic information about the participant; and (ii) the food and beverages the participant consumed in the last 24 hours either as part of a meal or as a snack. From the responses, detailed information about the nutritional profile of the participant is inferred. The questions are asked to the participants through a 5-step process called the Automated Multiple-Pass Method (AMPM). AMPM asks for the quick list of consumed food products, then probes for forgotten food products, then gathers consumption time and place of each food product. Finally CCHSN reviews 24-hr food consumption in detail with the participant and probes again for any forgotten food product. This 5 step method decreases the possibility of forgotten consumed products in the last 24 hours. At the end of the survey, the participant is invited for a follow-up survey. In both 2004 and 2015, approximately one third of the participants responded to a follow-up survey. In this study, only the first survey is analyzed as it contains more participants and so is more comprehensive.

2.1.3 Subset of Participant Attended

This study does not use the responses from all of the participants in this survey. Specifically, the selected participants in this study are as follows:

- *Ontarians:* Only the participants who reside in Ontario are selected.
- *Ages Above two:* Only the participants whose ages are above two are selected. It is assumed that participants with age below two have a low possibility of having established dietary preference of their own and therefore have an insignificant impact on both identifying food consumption and dietary patterns.
- *Exclusion of Brest-fed Participants in 2004:* Finally, regardless of their ages, any participant who indicated being breastfed in CCHSN 2004 is excluded. Recall that breastfed participants were already excluded from CCHSN 2015.

2.2 Evaluating 10-Year Change of Food Consumption

One of the goals of this study is to evaluate the 10-year change of food consumption in Ontario. Primarily, high-level groups of food products, such as beef, pork, or dairy, are studied instead of individual food products, such as onion vegetable soup, which are highly varied and less informative. To do so, we identified a set of 18 *high-level food groups* (HLG), which are shown in Table 3. The 2004 CCHSN survey includes approximately 7000 different individual food products that participants have mentioned. The survey categorizes each of these food products into 24 high-level groups (referred to as *CNF food group codes* in the survey). These 24 groups were a good starting point for the purposes of this study, but some of these groups were not specific enough to identify some food products for differentiating based on the animal-based ingredients they contained. For example, one of these groups was 'soups', which included both vegetable-based soups and meat-based soups that did not differentiate between the animal ingredient it contained. So, individual food products that belonged to those HLGs were assigned to other existing HLGs based on the animal ingredient each food product contained. For example, vegetable-based soups were assigned to 'vegetables' HLG and beef-based soups were assigned to 'beef' HLG. In the end, six of HLGs were re-classified. These re-classified HLGs are as follows: 'babyfoods', 'soups-sauces-gravies', 'lamb-veal-game', 'fast foods', 'mixed dishes' and 'unknown'. With the same approach, some food products were assigned to new HLG depending on the animal ingredient it contained including dairy when applicable. These re-assigned food products were mainly in the following HLGs: 'sausage', 'legumes', 'beverages' and 'vegetables'. For example, 'smoked pork sausage' was in 'sausage' and re-assigned to 'pork' HPG.

Table 3. List of High-level Food Groups with 18 codes

High Level Food Groups (HLGs)	
Code	**Description**
1	DAIRY_EGGS, dairy-based SOUP
2	SPICES_HERBS
4	FATS_OILS
5	POULTRY, SOUP with poultry, BABYFOODS with poultry, SAUSAGE only containing poultry
7	SAUSAGE_mixed (containing at least pork and beef)
8	CEREAL
9	FRUITS
10	PORK, SOUP with pork, BABYFOODS with pork, SAUSAGE only containing pork
11	VEGETABLES_excluding meat & dairy, SOUP with vegetables without meat
12	NUTS_SEEDS
13	BEEF, SOUP with beef, BABYFOODS with beef, SAUSAGE only containing beef
14	BEVERAGES_excluding meat & dairy
15	FISH, SOUP with fish, BABYFOODS with fish, SAUSAGE only containing fish
16	LEGUMES_excluding meat & dairy
18	BAKED
19	SWEETS
20	GRAINS
25	SNACKS

It was also of interest to this study to analyze changes in the consumption of the products that are processed differently within the same HLG. Similarly, it was of interest to this study to evaluate the changes of liquid-heavy version of the products, such as a soup vs main dish product, as it is expected that the liquid-heavy versions of products to have very less environmental impacts than non-liquid-heavy versions. To analyze these changes, first 18 HLGs were divided into 83 *low-level food groups* (LLGs). For example, the fish HLG was divided into three LLGs: 'raw fish', 'frozen fish', 'canned fish'. Similarly, the beef HLG was divided into two LLGs: 'beef' and 'beef soup'. The list of LLGs are shown in Table A1 in Appendix A.

The 10-year change of food consumption is evaluated by analyzing 2004 and 2015 CCHSN with the following steps:

1. *Determining HLG and LLG of each individual food product in participants' responses:* In 2004 and 2015 CCHSN, the individual food products mentioned in the responses of are shown by CNF Food Name codes. In total, 2004 and 2015 CCHSNs have approximately 7000 and 6000 different food products, respectively. Approximately 2700 and 2130 of these products were consumed by Ontarians in 2004 and 2015 CCHSN, respectively. After looking at the description of individual food product one by one, each food product was labeled to its corresponding HLG and LLG code.

For example, the individual food product 'soup, beef, broth, cubed, dehydrated' was labeled with the 'beef' HLG and 'beef soup' LLG.

2. *Calculating the average consumption of each HLG and LLG:* In CCHSN surveys, each participant has a *sampling weight*, which indicates the number of people the participant represents in the entire population according to participant's socio-demographic characteristics. For example a participant with a sampling weight of 200 represents 200 people from the socio-demographic class to which that particular participant belongs to in the population. Therefore, when calculating the average amount of consumption of each HLG and LLG by Ontarians, the average of the amount of food products consumed by the participants in those groups cannot be taken directly. Instead, a weighted average is calculated, where the amount of food each participant consumed was multiplied by the sampling weight of that participant.
3. *Comparing the results of 2004 and 2015 CCHSN to evaluate the 10-year changes:* Finally, for each HLG and LLG, the 10-year change of Ontarians' average food consumption is compared by using the calculated results from step 2 to determine if there is a significant change.

2.3 Evaluating 10-Year Change of Identified Dietary Patterns

Another goal of this study is to evaluate the 10-year change of dietary patterns in Ontario. Specifically, the changes in the following seven different patterns that were also used in the prior work by Veeramani (2017) was analyzed. In this analysis, it is assumed that participants' 24-hr recall responses reflected their typical dietary pattern. In the below definitions and the rest of this thesis, red meat refers to beef, pork, lamb, veal, and game meat products.

- *Vegan:* excludes all animal-based food products including dairy and eggs.
- *Vegetarian:* excludes all animal-based food products, but includes dairy and eggs.
- *Pescatarian:* excludes all meat products except fish.
- *No red meat:* excludes all red meat products, so consumes fish and poultry as meat products.
- *No beef:* excludes only beef-based products.
- *No Pork:* excludes only pork-based products.
- *Omnivorous*: all-inclusive diet without any restrictions.

Given these definitions, to determine the dietary pattern of a participant, it is necessary to determine whether the participant's diet excluded the following five food items: dairy-and-eggs, fish, poultry, pork-based meat, and beef-based meat. First, which of these food items are excluded in a participant's diet is identified, then the decision table given in Table 4 is used to determine which of the seven dietary patterns the participant belongs to. For example, the first row of the table indicates that if the diet excludes all of these five food items, then the participant is a vegan, because the participant must be eating only vegetable-based food and no dairy and eggs. Similarly, the second row indicates that if the diet excludes all of these five food items except dairy and eggs, the participant is a vegetarian. Specifically, the 10-year change of dietary patterns is evaluated as follows:

Table 4. Decision Table for identifying dietary pattern of a participant

Does a participant's responses exclude any of the following 5 food items?

DAIRY-and-EGGS	FISH	POULTRY	PORK	BEEF		DIETARY PATTERN
yes	yes	yes	yes	yes	→	**Vegan**
no	yes	yes	yes	yes	→	**Vegetarian**
no	no	yes	yes	yes	→	**Pescatarian**
no	no	no	yes	yes	→	**No Red Meat**
no	no	no	no	yes	→	**No Beef**
no	no	no	yes	no	→	**No Pork**
no	no	no	no	no	→	**Omnivorous**

1. *Determining the five food items excluded by each participant:* Similar to the approach from Section 2.2, approximately 2700 and 2130 individual food products in 2004 and 2015 CCHSNs, respectively, are assessed and labeled each one with one of the seven *dietary food groups (DFG)*. In the following list, the numbers in parentheses are the *ranks* of each DFG: vegetable (1); dairy-and-egg (2); fish (3); poultry (4); pork (5); beef (5); mixed-pork-beef (6). Many of these individual food products contain multiple ingredients. When a food product contained multiple items, the food product is labeled with the highest ranked DFG. For example, if a food product contained vegetable and dairy-and-egg, it was assigned the label dairy-and-egg, which has a rank 2, and not vegetable, which has a rank 1. That is because dairy-and-egg is more selective, as a person eating dairy-and-egg cannot be vegan whereas a person eating vegetable can be both vegan and vegetarian. Similarly if a food product contained both fish and beef, then it was labeled as beef, as a person eating beef cannot be pescatarian but a person eating fish can be pescetarian, no red meat, no-pork, or

omnivorous. Finally, when a dish contained both a pork-based meat and a beef-based meat, then it was labeled as mixed-pork-beef. The descriptions of some food products, such as 'Italian wedding soup', were not detailed enough to identify all ingredients, whether it contains an animal-based ingredient or not. For those food products, their ingredients were determined by looking at online cooking websites (www.foodnetwork.com, www.allerecipes.com, and www.geniuskitchen.com) and official food product websites.

2. *Identifying dietary patterns of each participant: Given the* DFG labels of each product, the decision-table is implemented in SPSS. The performed SPSS code is included in Supplement A1 in Appendix A. As described above, the code checks which food items the participant excludes and based on that assigns one of the dietary patterns to the participant.
3. *Calculating the frequency of each dietary pattern:* Similar to the approach from Section 2.2 (see step 1), weighted frequency calculation of each dietary pattern is performed for both 2004 and 2015 CCHSN. Recall that each participant in the 2004 and 2015 CCHSN has a sampling weight. The number of participants in each dietary group is counted for 2004 and 2015 CCHSN, each participant is multiplied with its sampling weight, and the number of participants in each dietary pattern is divided by the sum of the weights. This calculated the weighted frequency (or percentage) of Ontarians in each dietary pattern.
4. *Comparing the results of 2004 and 2015 CCHSN to evaluate the 10-year changes:* Finally, the 10-year change of Ontarians' dietary patterns calculated from step 3 is compared to determine if there is a significant change in Ontarians' dietary pattern preferences.

2.4 Life Cycle Assessment Methodology

The environmental impacts of dietary patterns of Ontarians are quantified by using LCA. LCA is a methodology that analyzes the inputs and the outputs of a product in its entire supply chain, from raw material extraction to disposal, in order to assess the environmental impacts associated with the whole production system of that product (Brune, 1997; Roy et al., 2009). In this study, products are represented by annual *food baskets* that are formulated for each dietary pattern. Specifically, for each dietary pattern, the average of consumed food products are calculated based on the responses of participants that belonged to that particular dietary pattern in 2015 CCHSN. Recall that participants' responses indicate their food consumption on one day. These averages are extrapolated from one day to one year average consumption, which formed the annual food basket for that dietary pattern. The details of food baskets are explained in Section 2.5.1. LCA is conducted by using SimaPro v.8.0.2 software and a database developed by Veeramani (2015) within that software.

This study is performed using the International Organization for Standardization's (ISO) latest guidance for LCA, which are specified in the ISO 14040 (2006) and ISO 14044 ((ISO, 2006b, p. 14044) standards. ISO standards require LCA studies to follow four steps: (1) define goal and scope of the study; (2) perform inventory analysis; (3) assess life cycle impacts; and (4) interpret the results of the study. The details of these steps are explained next.

2.4.1 Goal and Scope

One of the goals of this study is to inform and guide policy makers, professionals in food sector, and consumers about the environmental impacts of current food consumption of Ontarians, in particular the CF of dietary patterns. In addition, this study aims to find alternative diets that are more nutritionally balanced, low carbon and at the same time socially acceptable than existing ones.

ISO requires LCA studies to explain their scopes through four parameters: (1) functional unit; (2) system boundaries; (3) inventory analysis methodology; and (4) impact assessment methodology. These parameters are explained in the following sections.

2.4.1.1 Functional Unit

In LCA, the functional unit (FU) is a bridge between the function of a product and a reference measurement of the inputs and outputs of the system (Matthews, Hendrickson & Matthews, 2015). Defining the FU is a three-step process (Reap et al., 2008): (i) defining the primary function; (ii) identifying the FU; and (iii) defining the reference flow (RF).

(i) *Primary function of food baskets:* Within the LCA community studying food-related topics, there is no consensus on the primary function of food consumption. There are various suggestions for its function, such as providing nutrition, social interaction, and culture (Heller, Keoleian & Willett, 2013). In this study, the main function of a food basket is defined as providing nutrition to the body by focusing on energy, i.e., calories, and protein.

(ii) *FU of food baskets:* Based on the defined primary function of food consumption in previous step, two FUs are identified. These FUs are as follows:

1. T*raditional mass-based FU*: analyzes the weight and volume of food consumption.
2. *Calorie-based FU*: analyzes the calories of consumption by converting the consumed weight amount in grams to its corresponding calorie amount in kilocalories.

(iii) *RF of food baskets:* In LCA studies, RF shows the required amount of products to deliver the performance of the defined functional unit. Mainly, defining RF is important for comparing different products. Thus, the RF of food baskets is defined as 837,434 based on weighted daily calorie intake of Ontarians. This determined value makes the total calories of all food products existing in that dietary pattern for annual per-capita food consumption.

2.4.1.2 System Boundary

The system boundary of this study is defined as 'farm to fork', which assesses the environmental impacts of food baskets considering all stages of the supply chain of each food product in that basket. Specifically, the system boundary of this study includes the following stages: (1) upstream processes of production of fertilizers and pesticides; (2) food production processes at farm; (3) food transportation to processing facilities and retail; (4) processing of food products, such as packaging and canning; (5) transportation of consumers to food shopping; (6) food storage at home; (7) cooking; and (8) dishwashing. Within each stage, we also took food waste into consideration. We excluded the following stages due to missing information in available data: production of tangible assets (such as farm machinery, vehicles, buildings, cooking tools, and other), food storage and waste management along supply chain (such as port, transportation, distribution centers, and retail).

The geography of this study is Ontario, Canada, which is where the food consumption of the food baskets studied occurs. However, various products in these baskets are produced not just in Ontario but around the world. The production stages of the imported products were assessed using statistics on average imports over the past five years (Government of Canada, 2018b; Kissinger, 2012).

2.4.1.3 Impact Category

To estimate the environmental impacts of food baskets, this study analyzes greenhouse gas (GHGE) by using TRACI 2.1 impact assessment method. Specifically, the carbon dioxide (CO_2) equivalent of GHGE of each food basket over one hundred years is analyzed. This is called the 100-year Global Warming Potential of a product in the Intergovernmental Panel on Climate Change (IPCC) standards.

2.4.2 Collecting Data for Life Cycle Inventory

The *Life cycle inventory* (LCI) is composed of gathering data on all inputs and outputs associated with a product along its all production stages within the defined system boundary. Examples of inputs are raw materials and energy, and examples of outputs are wastes, by products and emissions to air, soil, and water. This inventory data becomes the database for further analysis of environmental impacts of the product studied.

The LCI of this study is gathered from three main resources: (i) CCHSN for formulating food baskets for each dietary pattern; (ii) the 'farm to fork' database developed by Veeramani (2017) for assessing environmental impacts of individual food products; and (iii) USDA Loss Adjusted Food Availability (USDA LAFA) for assessing food loss along food supply chain. Veeramani's database provides data for all stages of 'farm to fork' as described in Section 2.4.1.1. For the details of this database, see Veeramani (2015) Supplement 1 in Appendix B.

2.4.2.1 Formulating Annual Food Baskets for each Dietary Pattern

2.4.2.1.1 Formulating Actual Annual Food Baskets with traditional mass-based FU

To quantify the CF of dietary patterns, it is necessary to understand the amounts of individual food products consumed within each dietary pattern. To do so, annual food baskets are formulated for each of the seven dietary patterns. A food basket of a dietary pattern is intended to be representative of the average annual food consumption of Ontarians in that dietary pattern. For formulating the annual food basket of a dietary pattern, the following steps are performed. As a preliminary step, from datasets, only the participants within a single dietary pattern are filtered, say 'Omnivorous'.

(i) *Calculating the average consumption of each individual food product:* Similar to the approach applied in Section 2.2. (see step 1), the weighted average of each individual food product consumed by the participants in grams is calculated. As before, the amount of food each participant consumed is multiplied by the sampling weight of that participant.

(ii) *Identifying the important LLGs and most commonly consumed food products:* One of the concerns was to include the most commonly consumed individual food products in each basket. This is mainly because not all food products have published LCA studies, so there is lack of data availability for all food products consumed by participants. To pick the most commonly consumed individual food products in a thorough way, the following steps are applied. Recall that each food product is assigned to a LLG and a HLG and each LLG is part of one HLG. Using the average weighted consumption of each food product from step (i), the average consumption of each LLG and HLG is calculated. Then, the LLGs that contributed less than 5% of the total consumption of the HLG that they belong to are filtered out. For example, within the 'Dairy and Eggs' HLG, whose average weight was 290 grams, the 'Dairy Soup' LLG is filtered out because its average weight was 2.8 grams, which corresponds to 1% of total weight of 'Dairy and Eggs' HLG. Then, within each of the remaining LLGs, the most consumed individual food product is selected by looking at the number of people who consumed that individual food product. For example, for the 'Dairy Milk' LLG in the omnivorous dietary pattern, the most commonly consumed milk type is '2% partly skimmed milk'. It is assumed that each food baskets is limited to the identified most commonly consumed food products.

(iii) *Formulating annual food baskets:* Finally, we put all of the individual food products we identified into the food basket for the dietary pattern. The weight of each item was given initially as the weight of the LLG it represents. Recall that we had removed some LLGs. We distributed the weights of the LLGs proportionally to the food products representing the LLGs that are included in the food basket. For example, in 'No Pork' dietary pattern, the average weight of LLG 'Grain Others' is calculated as 2.44 gr and this LLG is excluded as it contributed only 5% to the total weight of HLG 'Grain'. After this exclusion, HLG 'Grain' remained with only two LLGs, 'Grain Rice' and 'Grain Wheat' whose average weight are calculated as 36 gr and 16 gr, respectively. The average weight of 'Grain Others' is redistributed among 'Grain Rice' and 'Grain wheat' proportionally. After redistributing the average weight of LLG 'Grain Others', the average weight of 'Grain Rice' increased by 1.7 gr and the average weight of 'Grain increased by 0.74 gr. Also note that in some cases, a food product in the food basket had no LCA data neither in the database developed by Veermani (2015) nor in other available resources, such as the latest Ecoinvent database. In these cases, one of the following two things applied to replace this product: (1) the next popular food product is selected from the LLG that particular food product represented; or (2) if there was another product, e.g., onion, in the basket that is similar to the food product that did not have LCA data, e.g., garlic, then the weight of garlic is added to the weight of onion. Lastly, the final average weight of identified most commonly consumed food products are extrapolated from one day to one year average consumption by multiplying with 365 that formed the annual food basket for that dietary pattern.

2.4.2.1.2 Calculating Calorie and Protein Intake of Actual Daily Food Baskets

To assess the nutritional profile of actual food baskets, the calorie and protein intakes of actual food baskets are calculated. Calorie and protein equivalence of actual daily food baskets are calculated by converting the weight of commonly consumed food products in these baskets to calories and protein amounts. To do this, the USDA nutrition database is used to calculate the conversions of a gram of a food product to calories and protein grams.

The calorie and protein daily intakes are compared with the results of corresponding food baskets from 2004 to understand whether there is a change in Ontarians' calorie and protein intake in the last decade. In addition, the daily calorie and protein intakes are compared with the calorie and protein recommendation levels of Canada's Food Guide to evaluate whether Ontarians consume more or less nutrition than what they are supposed to. These calorie and protein recommendation levels are determined based on the average recommendations for females and males at the age of 31 and 50 with the assumption of all participants had moderate exercise level. According to Canada's Food Guide, these are determined as 2,294 kilocalories and 51 gram protein per day (Health Canada, 2007). This assumption might have affected these determined values as intensity of exercise levels can increase or decrease the recommended amount of daily calorie and protein intakes (USDA, 2018b).

2.4.2.2 'Farm to Fork' Database for Individual Food Products

This study used the database developed by Veeramani (2015) for 74 different food products that includes information about all stages, farm to fork, of the production of these products. The information in the database is based on reviewed LCA studies. Specifically, this database includes the following stages: (1) food production at farm; (2) transportation of food products from production to sales point; (3) food processing; (4) packaging; (5) electricity grid; (6) consumer transportation for grocery shopping; (7) food storage and preparation at household level; and (8) food loss along food supply chain. Refer to Veeramani (2015) for details of each stage.

In order to focus only on impacts of food consumption, changes that might have occurred from 2004 to 2015 in any of these stages used in the database is not reflected. Thus, all 2004 and 2015 food baskets used identically the same database. For example, consider beef production at farm, if there was an improvement in terms of CF reductions for beef production in 2015, this is not revised in the database for 2015 food baskets, instead the information of beef production from 2004 is used for all 2004 and 2015 food baskets. This approach ensured that the CF changes of food baskets only demonstrated the changes due to food consumption, but not by any other factor.

In this study, only two stages of Veeramani's database is modified as follows: (1) electricity grid; and (2) food loss along food supply chain. The electricity grid mix is changed from 2013 to 2015 (Ontario Energy Board, 2016) to reflect the changes in energy production for the year of 2015 CCHSN.

This change is also applied to all 2004 actual and alternative scenario food baskets developed by Veeramani. The food loss data utilized in this study is explained in the next section.

2.4.2.3 Food Loss Along Food Supply Chain

In LCA studies, it is important to account for food losses for the stages included in the study to assess environmental impacts more accurately (Corrado et. al., 2017). At a specific stage, say retail, the amount of food losses defines the initial amount of product required as input to meet a target amount of output. For example, if 12% of broccoli is lost at retail stores, then for a consumer to purchase 1 kg of broccoli from a retail store, that retail store needs to purchase 1.14 kg of broccoli, meaning that for retail stage in LCA studies 1.14 kg of broccoli needs to be accounted as input so that the output of retail stage would be 1 kg of broccoli. Accounting for food losses becomes more important for farm to fork studies because the amount of food lost along food supply chain can be quite high. For example, in total 68% of the weight of oranges produced is lost along processing, retail, and household stages (USDA, 2018a).

In this study, for food losses, different data is used than the one in Veeramani's database. (refer to Table 2 in Veeramani (2015)'s Appendix B). The food loss data used in this study is applied to all 2004 and 2015 actual and alternative scenario food baskets. The food loss data used are based on 2 sources: (1) USDA Loss Adjusted Food Availability (USDA LAFA) (USDA, 2018a); and (2) FAO Cooking Yield report (Bognar, 2002). *USDA LAFA* is chosen based on the assumption that both developed North American countries, United States and Canada would have similar food losses along food supply chain.

USDA LAFA provides food loss information for various food products along 3 main stages, processing, retail, and household, of the food supply chain (USDA, 2018a). Specifically, at household stage, this data provided 2 different values by showing food waste due to (1) nonedible parts; and (2) cooking yields and uneaten parts, separately. To distinguish food loss of cooking yields from uneaten parts, the cooking yield data from FAO Cooking Yield report (Bognar, 2002) is used to calculate the loss from uneaten parts.

In addition, a simplified version of USDA LAFA data is utilized. USDA LAFA data provides information at food product level instead of providing information at higher food category level, e.g., HLGs, such as fruits, vegetables, and legumes. In LCA, there is a feature called global parameters that can automatize a value or a formula to be applied to more than one food product. This feature eases to proceed any changes to pre-determined values or formulas. To benefit from this feature, an average of food loss of food products in the same HLG is determined. For a HLG, if there were more than 3 different food loss values for the commonly consumed food products that were selected for the food baskets, then average food loss value for those products is calculated. For example, for the fruits HLG, non-edible food waste values were 4%, 5%, 6% for grape, banana and strawberry, respectively. The average of food waste is determined as 5% which is assigned to these three fruits as non-edible food waste value. The modified USDA LAFA data is included in Table A2 in Appendix A.

2.4.3 Sensitivity Analysis

In LCA studies, sensitivity analysis is conducted to assess the robustness of results by changing percentage value of a single input at a time and keeping other inputs constant (Wei et al., 2015). If the results change significantly with a small change, then it means that results are sensitive to that particular input. So, sensitivity analysis demonstrates to what extent the qualitative results are affected to quantitative changes of input data used.

2.4.3.1 Electricity Grid Mix

In this study, sensitivity analysis is performed for electricity grid mix to understand whether CF results would be changed significantly or not. Mainly, electricity was used in the following stages: production, processing, storage at home, cooking and dishwashing. Over the last 10 years, the electricity generation in Ontario became environmentally-friendly as the province phased out from coal and shifted towards to nuclear and renewable energies. This change resulted in significant reductions in CF of electricity generation by 81%. Recall from Section 2.4.2.2, this study uses the 2015 electricity grid mix to show impact of 2004 and 2015 food choices. In order to generate 1 kwh electricity, 2003 electricity grid mix emitted 0.41 kg CO_2 eq. per kwh, whereas the 2015 grid emitted 0.08 kg CO_2 eq. A sensitivity analysis was conducted to understand the potential changes in the analysis if the 2003 grid mix were used for impacts related to 2004 dietary patterns. By performing sensitivity analysis, CF reductions gained by using 2015 electricity grid mix was eliminated and CF of 2004 food consumption was quantified with its 2004 electricity grid mix.

2.4.4 Scenario Analysis

LCA studies also conduct what-if scenario analysis in order to understand how results would be changed in an alternative situation (Pesonen et al., 2000). This alternative situation is similar to the already studied situation but has a different context by changing the setting. Eventually, scenario analysis can compare the quantitative results of environmental impacts of two or more situations and determine which scenario would be less harmful for the environment.

2.4.4.1 Alternative Scenario: Formulating Annual Nutritionally-Balanced and Low Carbon Food Baskets

This study was interested in understanding the environmental impacts of an alternative scenario that is a *nutritionally-balanced* and *low carbon* food basket for each dietary pattern. When designing these baskets, the actual food baskets are adjusted in a limited way. To do so, a methodology adopted by Veeramani 2015, which also designed similar baskets, is adopted with a slight modification. Next, the definition of what nutritional balance means in this study's setting and how adjustments are limited to actual baskets are explained. Then, how nutritionally-balanced and low carbon baskets are formulated described.

- *Nutritionally-balanced diet:* In this study, a nutritionally-balanced diet meant a diet with two properties: (1) The recommended amount of calories that an individual should take is determined as 2,294 calories per day as described in previous Section 2.4.2.1.2. (2) The basket should contain the same amount of recommended servings of each food category for a nutritionally balanced diet by Canada's Food Guide (Health Canada, 2011a). These recommended servings are shown in Table 5. For example, according to Canada's Food Guide, one should consume at least 1 serving of orange vegetable per day. It is assumed that Ontarians refer to Canada's Food Guide as a source to obtain nutritionally-balanced diet. Note that these serving recommendations in Canada's Food Guide apply to any individual. The guide does not have different recommendations for different dietary patterns.

Table 5. Recommended annual servings of Canada's Food Guide for adults ages 19 to 50

Canada's Food Guide Main Categories	Recommended Annual Servings
Milk & Alternatives	**730**
Meat & Alternatives	**913**
At least 2 servings of Fish per week	***104***
Vegetables & Fruits	**2920**
At least 1 dark green vegetable (broccoli, lettuce) per day	***365***
At least 1 orange vegetable (carrot) per day	***365***
Grain Products	**2555**

- *Limitation to Actual Food Basket Adjustments:* Specifically, the actual food baskets are adjusted by reducing the consumption of any food product by less than 50%. For example, butter is a product that the Canada's Food Guide recommends to be consumed in a very limited amount, so considering this, the butter consumption of dietary patterns is reduced at most by 50% reduction. The only exception to this limitation was beverages, for which the reductions exceeded 50% limit. This limitation is performed based on the assumption that participants would accept to lower their consumption amount of particular food products, such as beef, butter, cheese and others by 50%.

- *Designing annual nutritionally balanced and low carbon baskets:* Finally, for each dietary pattern, an alternative scenario is designed that is nutritionally balanced and low carbon. First, for actual food basket of a dietary pattern, the actual servings of each food item is calculated based on the serving size information provided in the USDA nutrition database (USDA, 2018b). Then, each food item within main food category of the basket is adjusted to meet the annual recommended servings by Canada's Food Guide such that a) it would have exactly provide 2,294 calories per day; and b) none of the food products would be reduced by more than 50%; and c) whenever possible, food products with the lowest CF would be preferred. It is important to highlight that meeting conditions a) and b) was possible for each dietary pattern because 50% reduction provided enough flexibility in the adjustments that could be applied. With this approach, the assumption was that participants would consume total amount of annual recommended servings of each alternative scenario within 365 days.

2.5 Limitations

2.5.1 Limitations of CCHSN

CCHSN gives a good overall "snapshot" of Canadians' eating habits and their daily dietary preferences. Currently, this is the best available data on Canadians' food consumption. However, CCHSN mainly has two limitations:

(i) *Limitation of the data to one day consumption*: In order to assess a participant's usual food consumption, ideally one would need information about the participant's food consumption over a longer period of time, such as a month or a year. However, CCHNS reports participants' consumption on only one day. This is problematic because we had to extrapolate one day food consumption to a year as if this data represented participants' usual food consumption. The focus on one day food consumption misses the fluctuations in participants' daily and seasonal food preferences. For example, an omnivorous participant might have excluded beef and pork on the day of CCHSN, and be assigned to no red meat diet based on the responses given on

that particular day. Seasonality effect is similar to daily fluctuations. For example, a participant might consume only vegetables protein during summer, but include fish in their diet during winter. That particular participant would be assigned to two different diets, vegetarian or pescatarian, depending on the time of the year the survey is conducted. Consequently, extrapolating the food consumption and daily dietary preferences of CCHSN to a year may not accurately represent the usual consumption of the participants.

(ii) *Confidentiality restrictions affect the vegan food basket:* CCHSN regulations restrict information where less than 30 participants are in a group. After we assigned the participants their dietary patterns (see Section 2.3), there were less than 30 vegan participants. Therefore, when designing the vegan food basket we could not calculate their most commonly consumed food products as we did for other dietary patterns (see Section 2.5.1). It was assumed that dietary pattern of vegan and vegetarians would be similar. Thus, the most commonly consumed food products of the vegetarian diet, excluding dairy-and-eggs, are chosen to design the vegan food basket.

2.5.2 Limitations of LCA Methodology

LCA databases include inventory data about the full production processes for many food products. Using the full inventory data, one can assess various environmental impacts, such as CF, eutrophication (EU) and acidification (AC) of these products. The Ecoinvent database and Veeramani's database (2015) are used in this study. Veeramani's database includes information gathered from the publications of LCA studies on some products that do not exist in Ecoinvent. Three main limitations of these databases are identified as follows:

(i) *Unavailability of LCA inventory data of food products in the databases:* Some food products were completely missing from both Ecoinvent and Veeramani's database. The following missing products were excluded in this study: mustard, soy sauce, barbecue sauce, watermelon, pear, peach, mango, garlic, mushroom, cashew, lentils, various breakfast cereals, fish haddock, wine, almond drink, tortilla chips, popcorn, crackers, chocolate bars, honey and others.

(ii) *Missing environmental impact information on some food products:* There were several products, such as eggs, milk, chicken, fish and pork, that did not exist in Ecoinvent, but existed in Veeramani's database. However, Veeramani's database is limited to GWP and does not include information about other environmental impact categories, such as EU and AC. This is because Veeramani's database is developed by gathering information about the food products

from the publications of LCA studies, which mainly focus on GWP. Initially, this study aimed to assess different environmental impacts of dietary patterns, including EU and AC, but due to this limitation, this study only focused on CF of food products.

(iii) *Non-localized data on some processes:* The quality of existing databases is based on the life cycle inventories of each food product. To have high quality, all processes need to be regionalized to where that process is occurring. Veeramani (2015) thoroughly adopted life cycle inventories of food products from existing studies for processing, packaging, transportation where applicable. However, not all of these processes reflect their origin. The only exception is Canadian beef that included regionalized information on all stages of production.

2.5.3 Limitations of Nutritional Assessment of Actual Food Baskets

This study focuses on assessing two macro nutrients when evaluating the nutritional assessment of actual food baskets. Daily calorie and protein intake are compared with ideal daily intakes of each nutrient. However, it is acknowledged that macro nutrients are not limited to providing calorie and protein, but include other nutrients, such as fats, water, fiber and antioxidants, which is not studied in this thesis. However, nutritionally-balanced diets should also consider macronutrients and micronutrients to better understand the total nutrition obtained from food consumption that helps to improve health by food intakes.

2.5.4 Limitations of Nutritional Assessment of Nutritionally-Balanced Food Baskets

Canada's Food Guide is the only publicly available resource for Canadians to get information on how to achieve a nutritionally-balanced diet. This guide provides a general information on daily and weekly basis of food choices. However, this study identified two limitations of this guide.

(i) *Lack of automatized assessment of nutritionally-balanced food baskets:* Canada's Food Guide provides broad information on how to balance a diet by showing variety of food products for each high-level food category. For example, the recommended servings of meat and alternatives category is 2.5 per day for an adult. But, meat and alternatives category is composed of several food groups, such as animal-based products, legumes, egg, and nuts, each of which has various nutrient profile. Thus, this guide does not clarify explicitly the frequency or maximum amounts of consumption of low-level food groups within each high-level food groups to achieve a balanced diet. Due to that, nutritionally-balanced diet assessment could be performed manually, but not in an automatized way.

(i) *Lack of food guidance for specific dietary patterns:* Canada's Food Guide gives recommendations to have a balanced diet for individuals without dietary constraints that correspond to Omnivorous diet in this study. As a result, it does not specify guidance for specific dietary patterns, especially for plant-based diets. For example, only animal-based food products provide essential vitamin B_{12} naturally. Since vegans do not eat animal-based food products, Canada's Food Guide does not inform vegans about from which foods to get this essential nutrient, such as increasing consumption of vitamin B_{12} fortified soy beverages.

Chapter 3 Results

This chapter starts with presenting the results of 10-year changes of Ontarians' food consumption in Section 3.1. The changes of Ontarians' food consumption show whether the amount of Ontarians food consumption increased or decreased for different high-level food groups (HLG) and low-level food groups (LLG). Recall that HLGs and LLGs show food products at different levels from Section 2.2. Then, Section 3.2 presents the results of 10-year changes of Ontarians dietary patterns that show whether there is a change in Ontarians' preference for some diets over the others (for the descriptions of dietary patterns see Section 2.3). Section 3.3 shows the 10-year changes of Ontarians nutritional assessment by displaying the daily protein and calorie intake in actual food baskets of each dietary pattern. This analysis demonstrates whether Ontarians under or over consume the calorie and protein from their daily food intakes. Starting from Section 3.4, the results of LCA, specifically CF are presented. Section 3.4 shows the 10-year changes of CF of actual and alternative food baskets for all dietary patterns. This section highlights the dietary patterns with high and low CF and the changes in their CF over the last decade. Section 3.5 demonstrates which food products contribute most to the total CF of each dietary pattern and how individual food products' CF contribution is changing over the last 10 years. Finally, Section 3.6 provides the results of LCA sensitivity analysis of changing the electricity grid mix from 2015 grid to 2003 grid.

3.1 10-Year Change in Ontarians' Food Consumption

Table 6 and Table 7 show the changes of food consumption in Ontario for HLGs and LLGs, respectively. In the tables, the HLGs and LLGs are presented under the Canada's Food Guide main categories. These categories are different from the HLGs and LLGs defined in this study and are determined according to the nutritional profile of food groups by Health Canada. The main interesting changes that are observed are as follows.

In the last decade, major changes in animal-based foods can be observed. Ontarians have reduced their milk consumption by 27%, but have increased their egg consumption by 21% as presented in Table 6. Looking at the meat products, a shift towards consuming less red meat products can be observed. Specifically, Ontarians have decreased their beef, pork and sausage consumption by 29%, 11% and 31%, respectively and increased their poultry and fish consumption by 18% and 11%, respectively as shown in Table 6. A closer look at LLGs of beef and poultry in Table 7 shows that approximately 25% of these HLGs are composed of soups and sauces which are mostly water instead of eating it as a meat portion. If we assume that 20% of soup and sauce LLGs of beef and poultry are composed of non-liquid heavy meat products, then the LLG of beef is reduced by 26% instead of 29%, and the LLG of poultry only increases by 9% instead of 11%.

Table 6. 10-year change in Ontarians' food consumption for HLGs

Canada's Food Guide Categories	2004 Average Weight (grams/person/day)	2004 Share by Weight	2015 Average Weight (grams/person/day)	2015 Share by Weight	10-Year Change in Average Weight
Total	**2132**	**100%**	**1789**	**100%**	**-16%**
Milk & Alternatives	**294**	**28%**	**230**	**26%**	**-22%**
Milk	243	11%	178	10%	-27%
Cheese	26	1%	26	1%	-3%
Meat & Alternatives	**226**	**11%**	**222**	**12%**	**-2%**
Egg	20	1%	24	1%	21%
Beef	61	3%	43	2%	-29%
Pork	24	1%	21	1%	-11%
Sausage	7	0%	5	0%	-31%
Poultry	62	3%	73	4%	18%
Fish	18	1%	19	1%	11%
Legumes	31	1%	30	2%	-1%
Nuts and Seeds	4	0%	6	0%	43%
Vegetables & Fruits	**489**	**46%**	**409**	**46%**	**-16%**
Vegetables	221	10%	188	10%	-15%
Fruits	268	13%	221	12%	-17%
Grain Products	**225**	**16%**	**208**	**18%**	**-8%**
Baked Products	79	4%	89	5%	13%
Breakfast Cereals	29	1%	22	1%	-22%
Grains Products	117	5%	96	5%	-18%
Others	**897**	**42%**	**720**	**40%**	**-20%**
Beverages	793	37%	630	35%	-21%
Carbonated	*171*	*8%*	*103*	*6%*	*-40%*
Juices	*85*	*4%*	*55*	*3%*	*-35%*
Alcohol	*120*	*6%*	*95*	*5%*	*-21%*
Coffee and Tea	*416*	*20%*	*377*	*21%*	*-10%*
Snacks	10	0%	10	1%	1%
Sweets	55	3%	44	2%	-21%
Spices & Herbs	5	0%	3	0%	-32%
Fats & Oils	35	2%	33	2%	-6%

Ontarians have a tendency towards healthier food products as there is a decrease in consumption of food products high in sugar content and processed products, such as cold breakfast cereals, pasta, canned and frozen products (England National Health System, 2017). Instead, there is an increase in the consumption of food products that are fresh and raw as presented in Table 6 and Table 7.

Regarding sugar content, high-level sugar content food products, which are biscuits and cakes, soft drinks including juice and carbonated ones, alcoholic beverages and sweets, are decreasing up to 40% as shown in Table 7. Instead, the consumption of fresh fruit juices are increasing by 19%. In recent years, Health Canada has been promoting smoothies as healthy drinks (Health Canada, 2011b). This might be causing the increase in consumption of fresh fruits and frozen fruits and canned fruits by 5%, 18% and 93%, respectively, as those food groups can be used to prepare smoothies.

Mainly, there is a decrease in consumption of processed foods that are canned and frozen, such as fish, legumes, vegetables, and fresh fruits, by 3% to 82% reductions. The consumption of other processed foods, such as cold breakfast cereals, and pasta has decreased by 4% to 38%, whereas consumption of grains that consist of couscous, bulgur, and quinoa, which are low in glycemic index, have increased by 79% (Table 7).

Overall there is a decrease in the consumption of fats and oils. Vegetable oils, butter, and margarine are decreasing by on average 13%. The only exception among fats and oils is the salad dressing is increasing by 5%. This might imply that there is an increase in consumption of salads which could further explain why there is a decrease in the weight of vegetables that can be seen in Table 6. If Ontarians have switched to consuming vegetables more through salads which can be low in mass, but are nutritious, it would be expected to see a decrease in mass of vegetables consumed.

Table 7. 10-year change in Ontarians' food consumption for LLGs

Canada Food Guide Categories	2004 Average Weight (grams/person/day)	2004 Share by weight	2015 Average Weight (grams/person/day)	2015 Share by weight	10-Year Change in Average Weight
Total	2132	100%	1789	100%	-16%
Milk & Alternatives	294	27.6%	230	25.7%	-22%
Milk	243	11.4%	178	10.0%	-27%
Cheese	26	1.2%	26	1.4%	-3%
Yogurt	21	1.0%	21	1.2%	0%
Milk Others	4	0.2%	5	0.3%	32%
Meat & Alternatives	226	10.6%	222	12.4%	-2%
Egg	20	0.9%	24	1.3%	21%
Beef	61	2.9%	43	2.4%	-29%
Beef _ only meat	44	2.1%	33	1.8%	-25%
Beef_soup, sauce	17	0.8%	10	0.6%	-40%
Pork	24	1.1%	21	1.2%	-11%
Sausage	7	0.3%	5	0.3%	-31%
Poultry	62	2.9%	73	4.1%	18%
Poultry _ only meat	48	2.3%	51	2.9%	6%
Poultry_soup, sauce	13	0.6%	22	1.2%	63%
Fish	18	0.8%	19	1.1%	11%
Fish_cooked	7	0.3%	11	0.6%	57%
Fish_canned	4	0.2%	2	0.1%	-33%
Fish_farmed	2	0.1%	2	0.1%	26%
Fish_soup, sauce	3	0.1%	2	0.1%	-32%
Fish_Seafood	3	0.1%	3	0.1%	-13%
Legumes	31	1.4%	30	1.7%	-1%
Legumes_cooked	19	0.9%	18	1.0%	-2%
Legumes_canned	5	0.2%	5	0.3%	-3%
Legumes_frozen	3	0.1%	2	0.1%	-33%
Legumes_dry	1	0.1%	1	0.1%	33%
Legumes_soup	0	0.0%	1	0.0%	454%
Nuts and Seeds	4	0.2%	6	0.3%	43%
Vegetables & Fruits	489	45.8%	409	45.7%	-16%
Vegetables	221	10.4%	188	10.5%	-15%
Vegetables_raw	89	4.2%	79	4.4%	-11%
Vegetables_cooked	66	3.1%	56	3.1%	-16%
Vegetables_canned	31	1.4%	21	1.2%	-31%
Vegetables_frozen	19	0.9%	13	0.7%	-31%
Vegetables_soup, sauce	7	0.3%	15	0.8%	100%
Vegetable_Juices	8	0.4%	3	0.2%	-60%
Fruits	268	12.5%	221	12.4%	-17%
Fruits_raw	135	6.3%	141	7.9%	5%
Fruits_canned	7	0.3%	8	0.4%	18%
Fruits_frozen	2	0.1%	4	0.2%	93%
Fruit_Juices_fresh	36	1.7%	41	2.3%	14%
Fruit_Juices_can & bottle	63	3.0%	23	1.3%	-63%
Fruit_Juices_frozen	25	1.2%	5	0.3%	-82%
Grain Products	225	15.6%	208	17.8%	-8%
Baked Products	79	3.7%	89	5.0%	13%
Baked_bread & bagel	63	2.9%	72	4.0%	15%
Baked_biscuit & cake	12	0.6%	11	0.6%	-6%
Baked_cracker	3	0.1%	3	0.2%	19%
Baked_granola bar	2	0.1%	3	0.2%	49%
Breakfast Cereals	29	1.4%	22	1.3%	-22%
Cereal_Cold	10	0.5%	9	0.5%	-6%
Cereal_Hot	12	0.6%	13	0.7%	7%
Cereal_Others	7	0.3%	0	0.0%	-100%
Grains Products	117	5.5%	96	5.4%	-18%
Grains_Pasta	43	2.0%	26	1.5%	-38%
Grains_Rice	52	2.4%	47	2.6%	-10%
Grains_Wheat Flour	22	1.0%	21	1.2%	-4%
Grains_Others	1	0.1%	2	0.1%	79%
Others	897	42.1%	720	40.2%	-20%
Beverages	793	37.2%	630	35.2%	-21%
Beverages_carbonated	171	8.0%	103	5.8%	-40%
Beverages_juices	85	4.0%	55	3.1%	-35%
Beverages_alcohol	120	5.6%	95	5.3%	-21%
Beverages_coffee & tea	416	19.5%	377	21.0%	-10%
Snacks	10	0.5%	10	0.6%	1%
Sweets	55	2.6%	44	2.4%	-21%
Spices & Herbs	5	0.2%	3	0.2%	-32%
Fats & Oils	35	1.6%	33	1.9%	-6%
Fats_Butter	11	0.5%	11	0.6%	-3%
Fats_Shortening & Animal	5	0.2%	4	0.2%	-13%
Fats_Margarine	6	0.3%	5	0.3%	-14%
Fats_Salad Dressing	8	0.4%	8	0.5%	5%
Fats_Vegetable Oils	6	0.3%	5	0.3%	-12%

3.2 10-Year Change in Ontarians' Dietary Patterns

The results of dietary patterns of 2015 CCHSN, in Table 8, show that most Ontarians continue to prefer animal-based diet over a plant-based diet. The majority of population prefers 'Omnivorous', 'no Pork' and 'no Red Meat' diets constituting 25%, 24% and 22% of the population, respectively. This is followed by 'no Beef' diet, which is the choice of 17% of the population.

Ontarians' preferences for plant-based diets, including both vegetarian and vegan, did not change in the last 10 years. Similar to 2004, in 2015 more than 90% of Ontarians prefer an animal-based diet. However, within animal-based dietary patterns, current changes show that there is a shift in Ontarian's dietary preference towards consuming more poultry products rather than red meat products. More specifically, Omnivorous diet has decreased by 7%, whereas No Red Meat diet has increased by 5%. These shifts in these dietary preferences are reflected in the changes of red meat and poultry food consumption as explained in the previous section.

Vegan is the least common dietary pattern constituting 0.4% of the population. Pescatarian is the second least common dietary pattern constituting 5% of the population and the least common dietary pattern that consumes animal-based products.

Table 8. 10-year change in Ontarians' dietary patterns

Dietary Patterns	2004 Share (%)	2015 Share (%)	10 Year Change (%)
Omnivorous	31	25	⇩ -7%
No Pork	26	24	⇩ -1%
No Red Meat	17	22	⇧ 5%
No Beef	16	17	⇧ 1%
Pescatarian	3	5	⇧ 2%
Vegetarian	7	7	⇨ 0%
Vegan	0.4	0.4	⇨ 0%

3.3 10-Year Change based on Daily Protein and Calorie Intake

The change of actual daily calorie intake, in Figure 1**Error! Reference source not found.**, shows that Ontarians' daily calorie intake decreased in the last decade between 15% to 30% in all dietary patterns except No Red Meat and Vegan. This is very surprising because since 2004, the number of Canadian adults identified as obese has increased from 59% to 64% of the population in 2017 (Government of Canada, 2018a; Statistics Canada, 2015). However, Government of Canada, consistent with the finding of Figure 1, has also reported a 5% to 15% decline in the average daily calorie intake of Canadians (not just Ontarians that this thesis studies) for different ages (Government of Canada, 2017b). However, it is still not clearly known why there is a discrepancy where there is a decline in daily calorie intake reporting and yet an increase in obesity. To better understand the factors, further analysis will be conducted by Statistics Canada (Government of Canada, 2017b). A part of the explanation might be that many studies have concluded that in 24-hr recall studies, participants underestimate their energy intakes ranging between 15% to 25% (Aalbers, Baars, & Rikkert, 2013; Freedman et al., 2014; Subar et al., 2015). It is also reported that this underestimation level can be even higher than 30% across obese participants (Johnson, 2002).

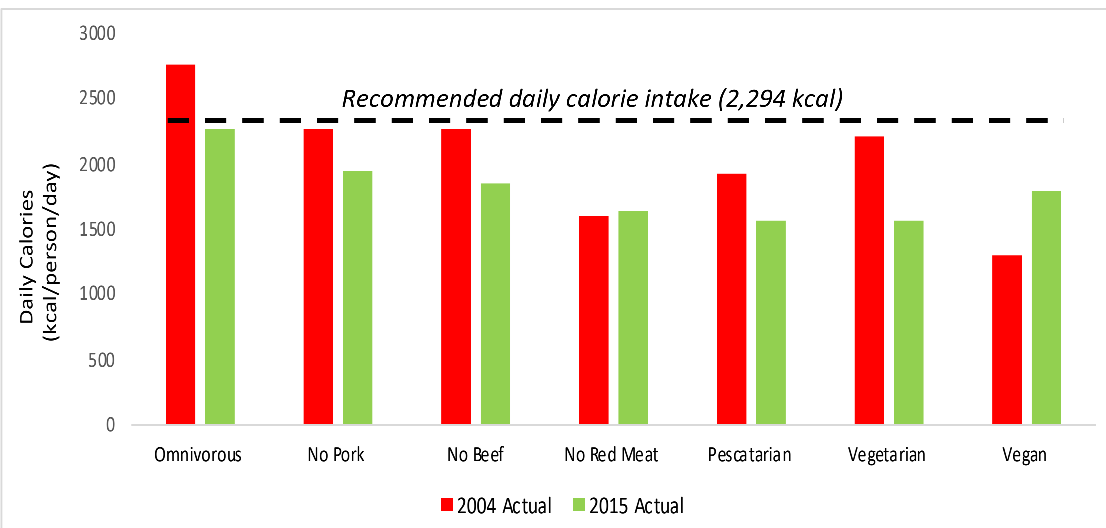


Figure 1. 10-year change based on daily calorie intake of food baskets

Unlike daily calorie intake, Ontarians' daily protein intake, shown in Figure 2, is increasing for all dietary patterns. The protein intake of no Red Meat and no Beef diets are growing fastest with over 25% increase. Similar to 2004 results, Ontarians continue to consume approximately two times more protein than the recommended daily intake of 51 protein grams (based on demographics of Ontarians) by Health Canada.

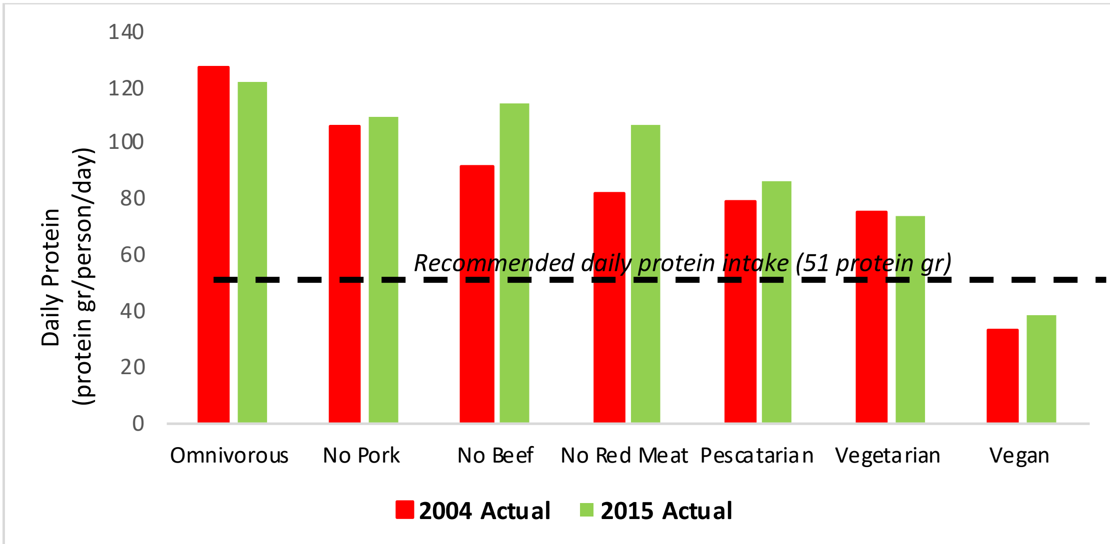


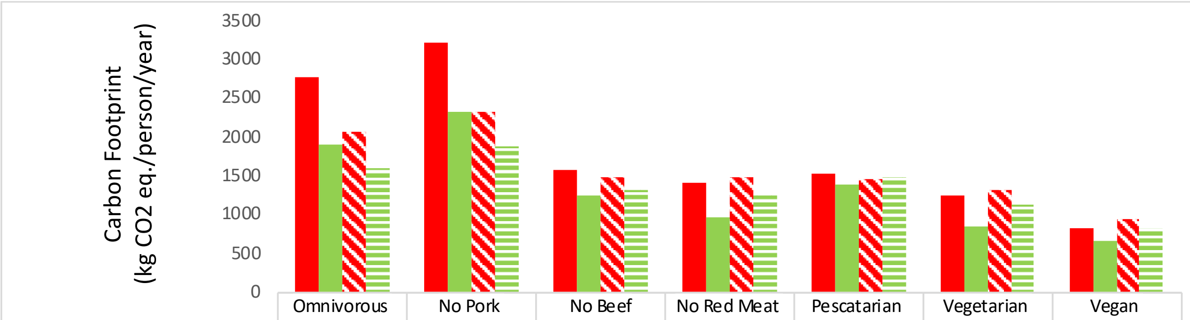
Figure 2. 10-year change based on daily protein intake of food baskets

3.4 10-Year Change in CF of Actual and Nutritionally-Balanced Food Baskets

In the last decade, the CF of annual actual and nutritionally-balanced food baskets decreased ranging between 10% and 33%, across all dietary patterns as shown in Figure 3. Among all dietary patterns, the only exception is the nutritionally-balanced pescatarian dietary pattern that increased by 1%.

Within actual food baskets, the highest CF reductions were in Omnivorous, No Pork, No Red Meat, and Vegetarian. The CF reductions of each dietary pattern is as follows: Omnivorous by 31%, No Pork by 28%, No Red Meat by 21%, Vegetarian by 33%, No Beef by 21%, and Vegan by 19%, and Pescatarian by 10%. Regardless of decreases, Omnivorous and No Pork food baskets continue to have the highest CF, which is approximately two times more than the CF of other food baskets.

Within nutritionally-balanced food baskets, the decrease in CF is slightly lower compared to the actual food baskets, with the highest decrease being 22%. The CF reductions of each dietary pattern is as follows: Omnivorous by 22%; No Pork by 19%, No Red Meat by 15%, Vegetarian by 13%, No Beef by 11%, and Vegan by 11%. Only Pescatarian increased by 1%.



	Omnivorous	No Pork	No Beef	No Red Meat	Pescatarian	Vegetarian	Vegan
2004 Actual	2768	3225	1570	1404	1534	1255	818
2015 Actual	1901	2317	1246	973	1376	845	660
2004 Nutritionally-Balanced	2062	2331	1469	1471	1457	1308	931
2015 Nutritonally-Balanced	1606	1889	1311	1249	1474	1134	825

Figure 3. 10-year change in CF of actual and nutritionally-balanced food baskets

3.5 10-Year Change in CF Contributions of Actual and Nutritionally-Balanced Food Baskets

In this section, the changes in annual actual and nutritionally-balanced food baskets are presented and the CF contributions are evaluated by focusing on the results of actual 2015 food baskets.

3.5.1 Animal-Based Dietary Patterns

In the last decade, the changes of CF contributions of animal-based dietary patterns, namely Omnivorous, No Pork, No Beef, No Red Meat and Pescatarian dietary patterns, show similarities. For that reason, the CF contribution of animal-based dietary patterns will be reviewed together. The CF change and CF contribution of Omnivorous are shown in Table 9 and Figure 4, respectively. The CF change and CF contribution of other dietary patterns are shown in Appendix B.

Among all categories, meat and alternatives continues to contribute the highest CF to the total CF of animal-based dietary patterns. In 2015, meat and alternatives category's contribution ranges between 27% to 64% to the total CF of each dietary patterns' entire food consumption where No Red Meat has the least and No Pork has the highest CF contribution. Specifically, meat products contribute highest to this category, while meat alternatives, such as eggs, legumes, nuts and seeds, contribute less than 6%, with variations in each dietary pattern. Not surprisingly, 'beef' is the food product with highest CF and has the highest CF contribution in Omnivorous and No Pork dietary patterns.

In terms of the 10-year changes, the CF of all animal-based diets show a significant decrease, ranging between 20% to 42%, both in actual and nutritionally-balanced food baskets. Particularly, in Omnivorous and No Pork dietary patterns, the changes in 'beef' food products have a significant effect as its contribution has decreased by 40% and 30%, respectively, since 2004. The only exception is the Pescatarian dietary pattern where the change in CF contribution of meat and alternatives has increased both in actual and nutritionally-balanced food baskets by 34% and 51%, respectively. The reason of this increase is that fish is a carbon-intensive food product relative to the other food products included in this dietary pattern and Pescatarians increased their consumption of fish by 25% by weight in the last decade. Thus, fish became the highest CF contributor in this dietary pattern, contributing 47% to the total CF.

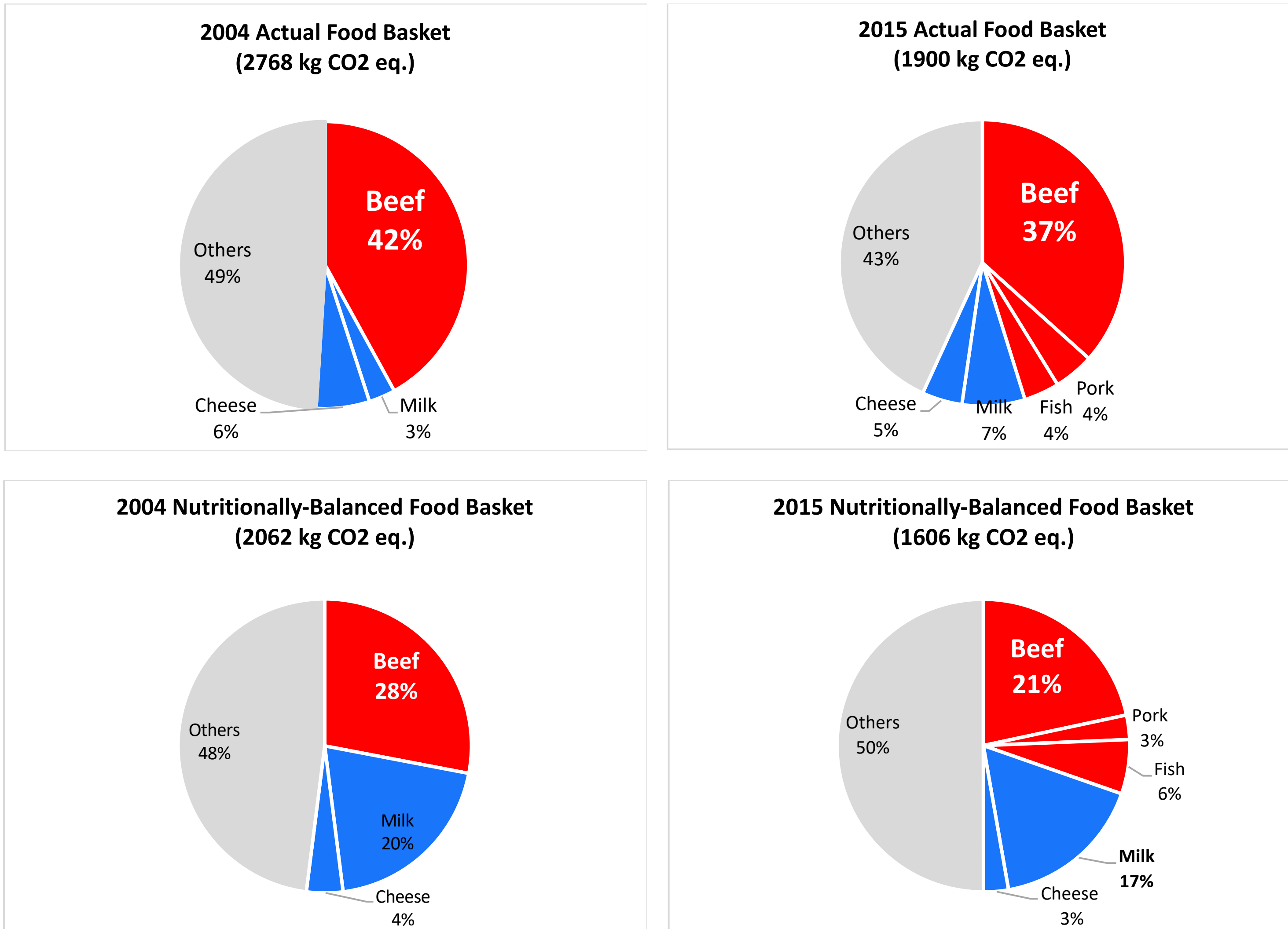
The second CF contribution in 2015 consumption comes from vegetables and fruits category. Within this category, the highest CF contributors are tomato sauce and greenhouse grown tomato and lettuce. Even though tomato sauce consists of field tomato that has low CF compared to greenhouse tomatoes, tomato sauce has the 5th highest CF among all food products in animal-based dietary patterns. The main reason is that tomato sauce has very high food loss along its supply chain. In total, 72% of all tomato that is used to produce tomato sauce is lost (USDA, 2018a). The main loss occurs at the processing stage where tomatoes are condensed to tomato sauce by evaporating its water content. The changes in CF contribution of vegetables and fruits category vary among these dietary patterns depending on the amount of consumed greenhouse grown vegetables. All of those dietary patterns have a significant decrease, ranging between 6% and 47%, in the last 10 years, except Omnivorous dietary pattern that is slightly increasing by 1%.

The other main CF contributing food category is milk and alternatives, such as cheese. The CF contribution of this category in 2015 varies between 8% and 17% among these dietary patterns. The 10-year changes of this category show a decrease for Omnivorous and Pescatarian dietary patterns, whereas an significant increase for No Pork, No Beef and No Red Meat dietary patterns.

Table 9. 10-year change in CF of annual actual and nutritionally-balanced Omnivorous dietary pattern

Canada's Food Guide Categories	Actual Food Basket: 2004 CF (kg CO_2 eq./person/year)	Actual Food Basket: 2015 CF (kg CO_2 eq./person/year)	Actual Food Basket: 10-Year Change in CF %	Nutritionally-Balanced Food Basket: 2004 CF (kg CO_2 eq./person/year)	Nutritionally-Balanced Food Basket: 2015 CF (kg CO_2 eq./person/year)	Nutritionally-Balanced Food Basket: 10-Year Change in CF %
Grand Total	**2768**	**1900**	**-31%**	**2062**	**1606**	**-22%**
Meat & Alternatives	**1572**	**963**	**-39%**	**849**	**558**	**-34%**
Meat Products	**1365**	**901**	**-34%**	**743**	**509**	**-32%**
Beef	1155	696	-40%	579	348	-40%
Pork	92	86	-6%	45	43	-5%
Chicken	46	44	-4%	23	22	-2%
Sausage	5	4	-18%	2	2	-7%
Fish	68	70	3%	93	93	0%
Egg	**196**	**44**	**-77%**	**95**	**25**	**-74%**
Nuts & Seeds	**8**	**14**	**82%**	**7**	**16**	**119%**
Legumes	**3**	**5**	**50%**	**3**	**8**	**173%**
Vegetables & Fruits	**330**	**334**	**1%**	**433**	**326**	**-25%**
Vegetables	**245**	**247**	**1%**	**290**	**231**	**-20%**
Tomato sauce	96	127	33%	96	66	-31%
Lettuce	118	46	-61%	64	23	-64%
Tomato	0	44	-	77	59	-23%
Onion	31	5	-85%	28	21	-26%
Carrot	0	1	-	10	14	37%
Pepper	-	10	-	-	10	-
Potato	-	13	-	-	7	-
Broccoli	-	-	-	15	30	100%
Fruits	**43**	**47**	**10%**	**104**	**60**	**-43%**
Fruit Juices	**43**	**41**	**-6%**	**39**	**36**	**-9%**
Milk & Alternative	**265**	**221**	**-16%**	**293**	**316**	**8%**
Milk	88	135	52%	202	272	34%
Cheese	176	87	-51%	91	44	-51%
Grains & Alternatives	**101**	**111**	**10%**	**205**	**202**	**-1%**
Others	**80**	**72**	**-10%**	**80**	**79**	**-1%**
Beverages	**91**	**97**	**7%**	**61**	**67**	**11%**
Fats & Oils	**307**	**77**	**-75%**	**127**	**48**	**-62%**
Snacks	**14**	**13**	**-7%**	**14**	**6**	**-53%**
Sweets	**9**	**11**	**23%**	**2**	**3**	**100%**

Figure 4. CF contribution of 2004 and 2015 annual actual and nutritionally-balanced Omnivorous dietary pattern



3.5.2 Plant-Based Dietary Patterns

Similar to animal-based dietary patterns, the CF change and CF contribution of plant based dietary patterns, Vegetarian and Vegan, will be reviewed together because they are very similar. The CF change and CF contribution of Vegetarian is shown in Table 10 and Figure 5, and the CF change and CF contribution of Vegan dietary pattern is included in Table B4 and Figure B4 in Appendix B.

The highest CF contribution of vegetarian and vegan dietary patterns both in 2015 actual and nutritionally-balanced baskets is from the vegetables and fruits category. These contributions range between 26% and 41% of total CF of each food basket. This is mainly due to exclusion of carbon-intensive meat products in these dietary patterns. Recall that vegetables and fruits were the second highest CF contributing food category for meat-based diets. Similar to the findings in animal-based dietary patterns, the main CF contributors within vegetables are tomato sauce, raw tomato and lettuce, contributing 90% and 85% of vegetarians and vegans' the total CF of vegetables sub-category, respectively. Looking at the 10-year changes of this category, a significant decrease can be observed for both actual and nutritionally-balanced food basket. Interestingly, the major decrease within fruits category of the Vegan pattern comes from reduced consumption of imported fruits, mainly papaya.

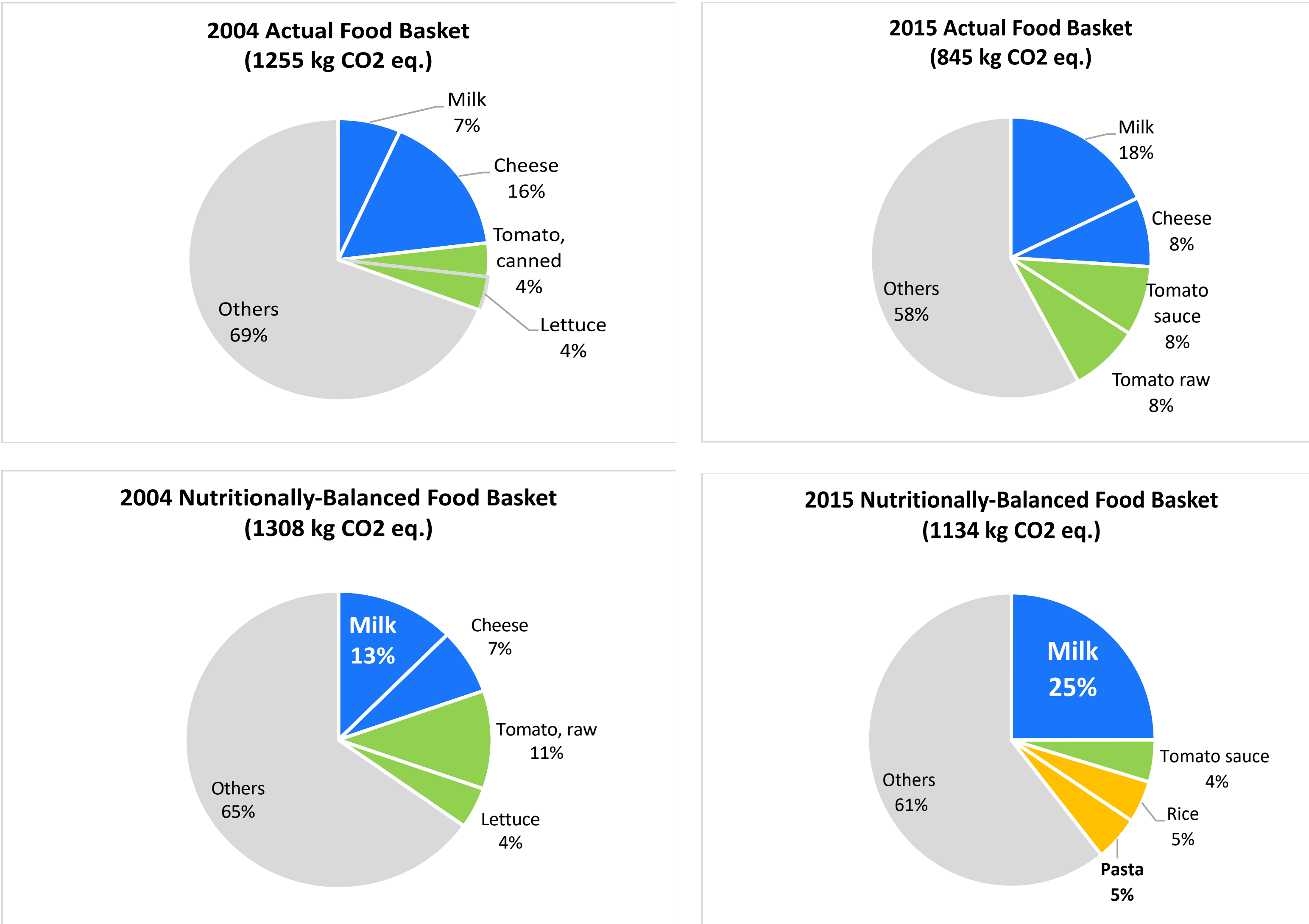
Specific to Vegetarians dietary pattern, milk and alternatives category has the second highest CF, contributing 26% to total CF. This is very close to the CF contribution of vegetables and fruits, which is 29%. In the last decade, CF contribution of this category decreased by 26% in actual food baskets and increased by 11% in nutritionally-balanced food baskets. The decrease in actual food baskets is due to reduced cheese consumption, whereas the increase in nutritionally-balanced food baskets is due to the adjustments applied based on Canada's Food Guide.

Grains category has the third highest CF contribution in Vegetarian dietary patterns, contributing 12% of the total CF, and the second highest CF contribution in Vegan dietary pattern, contributing 22% of the total CF. In the Vegetarian diet, the 10-year change in this category show a slight decrease by 2% in actual food baskets, whereas there is an increase by 14% in nutritionally-balanced food baskets. This increase is mainly due to adjusted oatmeal consumption to achieve nutritionally-balanced diets, while in the Vegan dietary pattern, this category has been increasing both in actual and nutritionally-balanced food baskets.

Table 10. 10-year change in CF of annual actual and nutritionally-balanced Vegetarian dietary pattern

Canada's Food Guide Categories	Actual Food Basket			Nutritionally-Balanced Food Basket		
	2004 CF (kg CO_2 eq./person/year)	2015 CF (kg CO_2 eq./person/year)	10-Year Change in CF %	2004 CF (kg CO_2 eq./person/year)	2015 CF (kg CO_2 eq./person/year)	10-Year Change in CF %
Grand Total	**1255**	**845**	**-33%**	**1308**	**1134**	-13%
Fruit and Vegetable	**273**	**248**	**-9%**	**444**	**300**	**-32%**
Vegetables	**190**	**188**	**-1%**	**324**	**216**	**-33%**
Tomato sauce	38	71	87%	31	53	72%
Tomato raw	40	64	58%	157	42	-73%
Tomato, canned	46	-	-	25	-	-
Lettuce	50	32	-36%	64	19	-69%
Potato	-	9	-	-	27	-
Pepper	-	7	-	-	17	-
Onion	12	3	-73%	23	20	-10%
Carrot	3	2	-52%	10	13	28%
Broccoli	-	-	-	15	25	68%
Fruits	**51**	**36**	**-30%**	**88**	**53**	**-40%**
Fruit Juices	**31**	**24**	**-23%**	**31**	**31**	**1%**
Milk & Alternative	**301**	**224**	**-26%**	**288**	**319**	**11%**
Milk	85	153	80%	180	283	57%
Cheese	216	71	-67%	108	35	-67%
Grains & Alternatives	**100**	**98**	**-2%**	**184**	**210**	**14%**
Bread	21	43	105%	41	49	19%
Rice	13	24	90%	42	52	25%
Pasta	19	17	-11%	37	57	53%
Wheat Flour	28	9	-68%	28	7	-74%
Oatmeal	-	3	-	4	42	1038%
Cereal, ready to eat	7	3	-61%	6	2	-63%
Toasted Bread	13	-	-	26	-	-
Others	**79**	**79**	**0%**	**79**	**80**	**0%**
Meat & Alternatives	**174**	**78**	**-55%**	**122**	**118**	**-4%**
Fats & Oils	**248**	**52**	**-79%**	**133**	**41**	**-69%**
Beverages	**62**	**50**	**-19%**	**45**	**62**	**37%**
Sweets	**7**	**9**	**29%**	**4**	**3**	**-28%**
Snacks	**10**	**7**	**-30%**	**10**	**3**	**-65%**

Figure 5. CF contribution of 2004 and 2015 annual actual and nutritionally-balanced Vegetarian dietary pattern

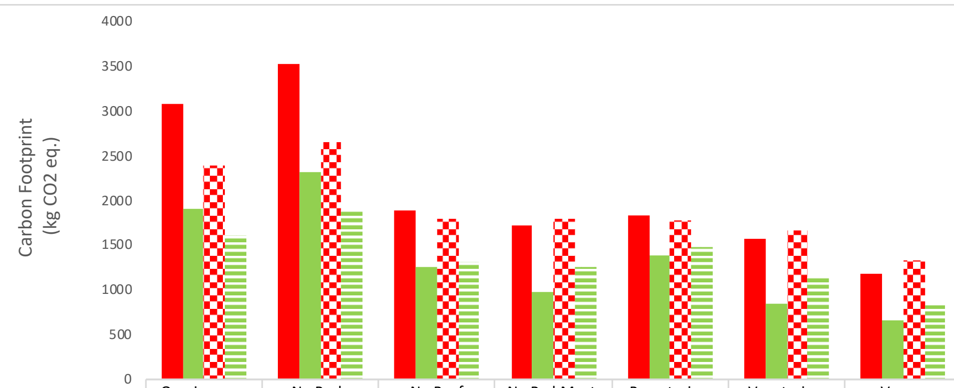


3.6 Sensitivity Analysis

3.6.1 Electricity Grid Mix

The electricity grid mix sensitivity analysis shows that the CF of all 2004 food baskets with 2003 electricity grid mix were on average 20% higher than with 2015 electricity grid mix (Figure 6). With the 2003 electricity grid mix, the CF of all actual food baskets would have decreased between 16% and 46% in the last decade. Recall from Section 3.4 that this decrease ranged between 10% and 33% with the 2015 grid mix. This analysis shows that using the 2003 electricity mix to represent the 2004 food baskets results in a larger decrease of CF between the 2004 and 2015 actual and nutritionally-balance diets.

In addition, these results indicate that electricity grid mix used is important to the CF of food baskets. Specifically, the total electricity used in production, processing, cooking, storage and dishwashing have impact on the total CF. The magnitude of this impact depends on whether and by how much the CF of electricity grid generation has increased or decreased.



	Omnivorous	No Pork	No Beef	No Red Meat	Pescatarian	Vegetarian	Vegan
2004 Actual w/2003 Electricity	3079	3529	1890	1723	1824	1559	1169
2015 Actual w/2015 Electricity	1901	2317	1246	973	1376	845	660
2004 Nutritonally-Balanced w/2003 Electricity	2380	2642	1793	1800	1764	1653	1329
2015 Nutritonally-Balanced w/2015 Electricity	1606	1889	1311	1249	1474	1134	825

Figure 6. CF of electricity grid mix sensitivity analysis for 2004 and 2015 food baskets

Chapter 4 Discussion

The main objective of this thesis was to evaluate the 10-year changes of both food consumption and CF of food consumption for different dietary patterns in Ontario.

The main contribution of this study is quantifying the changes of environmental impacts of food consumption over longer periods of time compared to previous studies, not only in Canada but also in other locations, that focus on the snapshot of environmental impacts of food consumption on shorter periods of time, typically one year or one month. These results give important information to policy-makers interested in Ontarians' health and changes in CF. Results show that Ontarians on at least two aspects depict a change towards healthier food consumption. Specifically, although the share of plant-based diets continue to be same, Ontarians consume less red meat products and less sugar intensive products in 2015 compared to 2004. However, Ontarians continue to consume excessive protein intake relative to the daily recommended levels by Canada's Food Guide. In terms of environmental impacts, the CF of Ontarians' food consumption also shows a decrease, mainly as a result of consuming less beef on average.

4.1 Changes in Food Consumption

To better understand the changes in Ontarians' food consumption, they are compared with changes in Canadians' food consumption.

Overall in Canada, consumers in 2015 seem to be consuming even more protein relative to recommended daily levels than in 2004 (Government of Canada, 2017b). A recent publication by the government of Canada shows that Canadians obtain more energy from protein-based products than carbohydrate-based products. Specifically, 17% of Canadians' daily energy intake comes from protein-based products. Likewise, the results of this thesis shows that Ontarians also continue to consume more than double of recommended daily protein intakes. This makes consumers responsible for significant amount of food waste not only through uneaten parts due to food spoilage and leftovers, but also for excreting protein by obtaining more than daily recommended levels as excessive protein cannot be stored in bodies (Tlusty & Tyedmers, 2015). It seems likely that overconsumption of protein continue to have similar trends unless nutrition experts and dietitians promote sustainable diets rich in plant-based products (Globalnews, 2017), such as Mediterranean diet that recommend to consume higher amounts of vegetables, fruits and healthy oils and moderate amount of meat products compared to the other protein-rich diets. This approach of limiting meat products lead to lowering daily protein intake.

Global trends show that Canadians are still major beef consumers worldwide (Cook, 2018), ranking in 8th place of all countries reviewed. Nevertheless, Ontario consumers are reducing per capita meat consumption, particularly in two red meat products: beef and pork. Specifically, this study showed that Ontarians have increased poultry consumption by 9% and reduced beef and pork by 26% and 11%, respectively which is similar to national levels that show Canadians' poultry consumption increased by 7%, and beef and pork consumption decreased by 22% and 14%, respectively (Agriculture and Agri-Food Canada, 2018). This shift might be due to financial, health or environmental concerns or changing cultural and demographic characteristics (Statista, 2015). Additionally, food producers and market analysts consider that this is due to poultry being perceived as a healthier and affordable meat alternative compared to red meat products (Gundlock, 2018). Despite the decrease in consumption of red meat in Canada, Canadian red meat industry continues to grow by exporting to other countries (Agriculture and Agri-Food Canada, 2016a; Farm Credict Canada, 2017) that results in increasing total GHGE attributed to red meat industry in Canada.

According to the Canadian trends observed in Agriculture and Agri-Food Canada, the only discrepancy between Canadian and Ontarian trends is identified for fish consumption. In the last 10-years, Canadian fish consumption decreased by 12%, whereas Ontarians fish consumption increased by 11%. Again, this may be due to cultural differences in Ontario having more diversity or increased awareness of health implications of fish consumption.

In Ontario, milk consumption decreased by 27% and eggs by 3%, and is similar across Canada, where milk consumption has decreased by 20% and egg consumption has increased by 9% (Agriculture and Agri-Food Canada, 2018; Government of Canada, 2017a). Decreased milk consumption may be due to the aging population, or a change in ethnicities, such that people may be substituting milk with alternatives, such as almond, soy milk (Government of Canada, 2017). Additionally, it could be for health reasons, since Zaitlin (2013) found that people reduced milk consumption due to perceptions around lactose-intolerance, and a correlation of milk and asthma and allergies (Zaitlin et al., 2013). In terms of increased egg consumption, it is possible that protein-rich diets, such as Dukan, Paleo, and Keto, have been a factor as eggs are an affordable protein source (Agriculture and Agri-Food Canada, 2017).

Canadians are shifting towards drinks that contain less sugar. For Canadian consumers, consuming products with low sugar content is the second important factor for a healthy diet. 49% of consumers tend to purchase low sugar food products and beverages (Nielsen, 2018). Similar to 10-year changes identified in this thesis, also soft drinks consumption in Canada shows a 32% decrease (Statista, 2018).

4.2 Comparing CF of 2015 Dietary Patterns with Other Studies

Changes in Ontarians' food intake resulted in a reduction in Ontarians' CF by 28% over a 10-year period. The main CF reductions are attributed to a significant decrease in red meat consumption, specifically beef that has the highest CF among all food products and reported to be consumed by half of Ontarians in CCHSN 2015. An important thing is that although Ontario meat consumption, and particularly red meat, may be decreasing, this may not be observed in other provinces of Canada, such as in Alberta, British Colombia, Nova Scotia, and Saskatchewan. In those provinces, per household expenditure on beef increased more than 35%, whereas their expenditure on food increased around 10% from 2010 to 2015, whereas Ontarians spending increased by 10% both for beef and food (Statistics Canada, 2017e). That results in an increasing shift in beef consumption for those specific provinces. Thus, changing Canadian diets to reduce environmental impacts should focus on all provinces, not only on Ontario.

Among all studies reviewed, only Gill, Feliciano, Macdiarmid, & Smith (2015) identified the food products that have an increasing trend in terms of per capita consumption by weight and their associated impacts on the environment. Similar to findings of this study, Gill et al. (2015) concluded beef as the main contributor to CF of Brazilians' food choices. Unlike CF trends of beef in this study, in Brazil, beef has significant responsibility in the increase of CF of food consumption as the trends of per capita beef consumption has doubled in weight in the last decade.

The CF of this study are lower than those found in recent European studies with the same system boundary as this thesis, except for the findings of Biesbroek et al. (2018) and Rosi et al. (2017) (Table 11). The CF of Omnivorous dietary pattern of this study is approximately 30% higher than the findings of both studies. In Biesbroek's study, 73% of the participants were women compared to 50% of participants in this study, and women do not consume as much food as men consume. For Rosi's study, this might be due to lower consumption of meat products in the prevalent Mediterranean diet in Italy.

China, which is a developing country, has the lowest CF of Omnivorous diet among all studies reviewed in Table 11. The main reason seems to be the composition of their food consumption that is heavily based on vegetables and grains with very low amount of meat products, specifically beef products (Song, Li, Semakula, & Zhang, 2015).

Among the studies with the same system boundary as this thesis, the highest CF difference is observed with the results of Eberle & Fels (2016) that was quantified as 2.75 kg CO_2 eq. The CF of Omnivorous diet in this thesis is 31% lower than the findings of Eberle & Fels (2016). There might be two main reasons for this difference: (1) Eberle's study obtains food consumption data from national statistics that include all food waste and losses occurring along food supply chain whereas, this thesis obtains data from self-reported surveys, for which it is observed that participants tend to under-report their food consumption (Aalbers, Baars, & Rikkert, 2013; Freedman et al., 2014; Subar et al., 2015), (2) along food supply chain, unlike this thesis, storage at retail and waste management after consumption are also considered in Eberle's study.

It should be noted that these positive changes only hold at per-capita level. The changes in average Ontario's CF per-capita has decreased by 17%. Because Ontario's population has increased by 11%, the absolute CF of Ontario due to food consumption has decreased more slowly than the decrease observed in per-capita trends. Once the population effect is considered, the absolute CF shows a decrease by 8% instead of 17% in the last decade, which means that if Ontario strives to meet its climate targets, per capita CF needs to decrease even more. This becomes more important once Ontario's population projections are considered for the next 25 years. It is estimated that the population will grow by 32% (Government of Ontario, 2017). If CF of food consumption per capita remains the same, then Ontarians' absolute CF will increase by 32%.

When interpreting the results of the Vegan diet, it is important to note the following. Recall from Section 2.5.1 that CCHSN restricts the usage of information about groups containing fewer than 30 participants, which was the case for Vegan dietary pattern. Due to this confidentiality regulations, the most commonly consumed food products from the Vegan participants could not be used. Instead, the Vegan diet's consumed products were formulated based on estimations from the Vegetarian diet, which is the diet closest to the Vegan diet. Furthermore, it is likely that the statistical significance of results from fewer than 30 samples is low.

Table 11. Comparison of CF of unbalanced and nutritionally-balanced Omnivorous diet studies

Reference	Location	Omn. Unbalanced (kg CO_2 eq.)	Omn. Nutritionally-Balanced (kg CO_2 eq.)	Data Collection Food Consumption	CF Life Cycle Inventory	System Boundary
This study	*Ontario*	*1901*	*1606*	*Self-reported*	*LCA studies*	*production to consumption*
Eberle and Fels (2015)	Germany	2750	-	National Statistics	Gemis & Ecoinvent	production to consumption
Hyland et. al. (2017)	Ireland	2380	-	Self-reported	LCA studies	production to consumption
van de Kamp et. al. (2017)	Netherlands	2282	1875	Self-reported	Agri-footprint	production to consumption
Pairotti et. al. (2015)	Italy	2010	1964	National Statistics	Input-Output Analysis	production to consumption
Abeliotis et. al. (2016)	Greece	1827	1380	National Statistics	Barilla	production
Perignon et. al. (2016)	France	1563	-	Self-reported	Input-Output Analysis	production to consumption
Biesborek et. al. (2018)	Netherlands	1482	-	Self-reported	Agri-footprint	production to consumption
Rosi et. al. (2017)	Italy	1445	-	Self-reported	Barilla	production to consumption
Treu et. al. (2017)	Germany	1250	-	Self-reported	LCA studies	production
Song et. al. (2017)	China	1199	875	Self-reported	Barilla	production to retail

4.3 Environmental Impacts of Food Products

Among all food products, CF of animal-based products contribute the highest in many studies (Abeliotis, Costarelli, & Anagnostopoulos, 2016; Lacour et al., 2018; Rosi et al., 2017; Treu et al., 2017) ranging between 60% to 80% similar to the finding of this thesis. Specifically, beef has the highest CF contribution being approximately 15 times more than that of poultry. Moreover, beef not only contributes highest to the CF, but also to the other environmental impacts, such as WF and LU (Eberle & Fels, 2016; Treu et al., 2017). With the technological improvement since 1981 Canadian beef production has reduced its environmental impacts per one kg beef produced. Specifically, CF and WF of one kg beef decreased by 14% and 20%, respectively (Legesse et al., 2016; Getahun Legesse et al., 2018). However, these improvements are still not enough to mitigate the absolute environmental impacts of beef production. This is mainly because total beef demand is increasing more than per animal impact reductions. Therefore, global beef consumption needs to be lowered to reduce absolute environmental impacts associated with beef production.

Within Ontarians' dietary patterns, greenhouse vegetables have higher CF contribution compared to other vegetables. This is because production of Canadian greenhouse vegetables, relative compared to other locations, such as Spain, Italy and Morocco, requires providing warmer climate for a longer period of time inside the greenhouse infrastructure as shown in Table 12. Greenhouse vegetables production has been growing more than 20% in the last decade (Agriculture and Agri-Food

Canada, 2016b). Among all provinces, Ontario produces 61% of Canada's greenhouse vegetables (Agriculture and Agri-Food Canada, 2016b). The main greenhouse vegetables are tomatoes, peppers, and cucumbers, that in total represent 97% of total greenhouse vegetables (Agriculture and Agri-Food Canada, 2016b). More than 80% of these vegetables consumed fresh are produced in greenhouses, instead of field production (OMAFRA, 2018b). Among all fresh vegetables exported in Canada, 41% of those are grown in greenhouses (Agriculture and Agri-Food Canada, 2016b). Based on the changes, GHGE of greenhouse vegetables will continue to grow due to both high demand in Canada and abroad.

Table 12. Comparison of CF of tomato production in heated and unheated for different studies

Location	Greenhouse	Tomato CF (kg CO_2 eq./1 kg of tomato)	Reference
Ontario	Heated	3.2	Dias et al. (2017)
Italy	Heated	2.3	Almeida et al. (2014)
Spain	Heated	2.07	Perez Neira et al. (2018)
Spain	Unheated	1.13	Perez Neira et al. (2018)
Morocco	Unheated	0.55	Payen et al. (2015)
Spain	Unheated	0.24	Torellas et al. (2012)

This research could not assess environmental impacts other than CF. However, it is likely that the results for WF, biodiversity loss, for animal products, specifically for beef, would have similar trends as the CF results. Examples of prior studies that found high impacts for animal products are Fresán et al. (2018), Rosi et al. (2017) and Notarnicola, Sala, et al. (2017).

4.4 Future Research Opportunities

There are several research opportunities to better understand the implications of food consumption on both the health of environment and humans.

One of the opportunities is to use a detailed nutrition assessment method to assess nutritional profile of actual food consumption and nutritionally-balanced diets. Canada's Food Guide provides information on daily intakes of food servings for different food groups based on these groups' main nutrients. One of the limitations of Canada's Food Guide is that it does not provide detailed information on the macronutrient and micronutrient daily intake limits that constraint the assessment of nutritional profile of food consumption. To achieve a detailed nutrient assessment, Nutrient Balance Concept developed by Fern et al. (2015) could be used. This new concept quantifies macronutrients and micronutrients of a food or a diet while considering the quality of combinations of existing nutrients by algorithms. This new concept can also serve as functional unit when formulating food baskets instead of calculating functional unit of food baskets only based on calories.

Lastly, using a statistical method to group dietary patterns by looking at the amounts of specific food products rather than types of food products based on different dietary choices might provide realistic and practical information on the current situation of food consumption changes in Canada.

4.5 Recommendations

Recommendations for decision makers, food sector, and consumers are as follows:

Decision-makers:

- Incentivize a reduction in consumption of animal-based products, specifically beef and excessive amount of protein intakes. For example, government can implement taxes for carbon-intensive food products, such as beef products and nutritionists can promote plant-based diets that are not heavy in protein intakes to public.
- Support diet-environment related research that would focus on finding innovative ways to reduce agricultural pressure on the environment through changes in consumption.
- Health Canada should adjust Canada's Food Guide so that the meat and alternatives category would be called healthy proteins. This would help change the perception that one needs to eat meat to obtain protein. This would also lower excessive amount of protein intakes obtained from both meat and milk alternatives categories.

Retail sector:

- At retail stores, alternative marketing strategies would shift towards low-carbon and healthy products. An example would be to design cross-promotions for the following low-carbon and healthy products such as legumes, poultry, eggs, vegetables and fruits.

Restaurants:

- In menus, include healthy plates that are composed of healthy proteins, such as legumes, and combine with appropriate amounts of vegetables. In addition, menus could provide information on nutrient facts and environmental impacts of those plates.

NGOs working on food issues:

- To increase informed food purchase, NGOs could create awareness campaigns that would inform consumers of (i) the effects of food consumption on the health of humans and the environment; and (ii) the nutrient facts of dairy and eggs and plant-based food products, specifically protein content.

Consumers:

- Consume fewer food products with high CF, such as beef, greenhouse vegetables, milk, cheese, and imported products.
- For daily food consumption, account for protein content of all animal-based products, not just meat, to lower extensive daily protein intakes and reduce protein losses through waste.

Chapter 5 Conclusion

The changes in Ontarians' food consumption seem to be reducing meat intake, but there is still extensive amount of protein intake obtained through non-meat products, such as milk, cheese and others. In addition, Ontarians seem to be shifting towards healthier and less carbon-intensive meat products by consuming more no red meat products and less red meat products, specifically beef. This shows that consumers' food choices can change over time, and even towards healthier and less carbon-intensive alternatives. Thus, consumers, being the end users, can play a significant role by making sustainable decisions, such as consuming less animal-based food products, choosing seasonal food products. Animal products and greenhouse vegetable production continue to be hot spots in CF of dietary patterns. Three broad immediate directions of further research is outlined. First is to extend this study to the other provinces in Canada and to environmental impacts other than CF, such as WF and land use. Second is to assess nutritional profile of food consumption by considering all macro and micro nutrients in LCA studies. Finally, food waste is a very serious factor in determining the environmental impacts of food consumption and there are very few studies on food waste in Canada.

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Appendix A

Table A1. List of High-level and Low-level Food Groups

High Level Food Groups (HLGs)		Low Level Food Groups (LLGs)
Code	**Description**	**Description**
1	DAIRY_EGGS, dairy-based SOUP	DAIRY_Butter ,DAIRY_Cheese DAIRY_Cream, DAIRY_Egg DAIRY_Milk, DAIRY_Milk_Drink DAIRY_Milk_Powder,DAIRY_Soup_Sauce DAIRY_Yogurt
2	SPICES_HERBS	SPICES_HERBS
4	FATS_OILS	FATS_OILS_Animal, FATS_OILS_Margarine FATS_OILS_Salad_Dressing, FATS_OILS_Shortenning FATS_OILS_Vegetable
5	POULTRY, SOUP with poultry, BABYFOODS with poultry, SAUSAGE only containing poultry	POULTRY POULTRY_Soup_Gravy
7	SAUSAGE_mixed (containing at least pork and beef)	SAUSAGE SAUSAGE_Soup_Gravy
8	CEREAL	CEREAL_Corn_Rice, CEREAL_Granola CEREAL_Multigrain,CEREAL_Multigrain_Raw CEREAL_Oats, CEREAL_Oats_Raw CEREAL_Wheat
9	FRUITS	FRUITS_Canned, FRUITS_Dried FRUITS_Frozen, FRUITS_Raw FRUITS_Others, FRUITS_Juices_Canned FRUITS_Juices_Frozen, FRUITS_Juices_Raw
10	PORK, SOUP with pork, BABYFOODS with pork, SAUSAGE only containing pork	PORK PORK_Soup_Gravy
11	VEGETABLES_excluding meat & dairy, SOUP with vegetables without meat	VEGETABLES_Soup_Gravy, VEGETABLES_Canned VEGETABLES_Cooked, VEGETABLES_Dried VEGETABLES_Frozen, VEGETABLES_Juice_Canned VEGETABLES_Raw
12	NUTS_SEEDS	NUTS_SEEDS_Dried, NUTS_SEEDS_Processed NUTS_SEEDS_Raw
13	BEEF, SOUP with beef, BABYFOODS with beef, SAUSAGE only containing beef	BEEF BEEF_Soup_Gravy
14	BEVERAGES_excluding meat & dairy	BEVERAGES_Alcohol, BEVERAGES_Carbonated BEVERAGES_Coffee, BEVERAGES_Juice BEVERAGES_Tea
15	FISH, SOUP with fish, BABYFOODS with fish, SAUSAGE only containing fish	FISH_Canned, FISH_Farmed FISH_Soup_Sauce, FISH_Wild SEAFOOD_Canned, SEAFOOD_Farmed SEAFOOD_Wild
16	LEGUMES_excluding meat & dairy	LEGUMES_Processed, LEGUMES_Canned LEGUMES_Cooked, LEGUMES_Frozen LEGUMES_Raw, LEGUMES_Soup
18	BAKED	BAKED_Biscuit_Cookie, BAKED_Bread_Bagel BAKED_Cake_Muffin, BAKED_Cracker BAKED_Granola_Bar, BAKED_Leavening
19	SWEETS	SWEETS_Candies, SWEETS_Dessert SWEETS_Others
20	GRAINS	GRAINS_Corn, GRAINS_Others GRAINS_Pasta, GRAINS_Rice GRAINS_Wheat
25	SNACKS	SNACKS

Supplement A1. SPSS Code used for identifying dietary pattern of each participant

```
DATASET ACTIVATE DataSet1.
STRING DietaryChoice(A27).
DO IF (DAIRY-and-EGGS EQ 0 and FISH EQ 0 and POULTRY EQ 0 and PORK EQ 0 and BEEF EQ 0 and MIXED-Pork-Beef EQ 0).
 COMPUTE DietaryChoice='Vegan'.
ELSE IF (FISH EQ 0 and POULTRY EQ 0 and PORK EQ 0 and BEEF EQ 0 and MIXED-Pork-Beef EQ 0).
  COMPUTE DietaryChoice='Vegetarian'.
ELSE IF (FISH GT 0 and POULTRY EQ 0 and PORK EQ 0 and BEEF EQ 0 and MIXED-Pork-Beef EQ 0).
  COMPUTE DietaryChoice='Pescatarian'.
ELSE IF (POULTRY GT 0 and PORK EQ 0 and BEEF EQ 0 and MIXED-Pork-Beef EQ 0).
  COMPUTE DietaryChoice='NoRedMeat'.
ELSE IF (PORK GT 0 and BEEF EQ 0 and MIXED-Pork-Beef EQ 0).
  COMPUTE DietaryChoice='NoBeef'.
ELSE IF (BEEF GT 0 and PORK EQ 0 and MIXED-Pork-Beef EQ 0).
  COMPUTE DietaryChoice='NoPork'.
ELSE.
  COMPUTE DietaryChoice='Omnivorous'.
END IF.
EXECUTE
```

Table A2. Food Loss along Food Supply Chain taken from USDA LAFA

*Values from Veeramani (2015) **Values assumed from similar food products in USDA LAFA

Commonly Consumed Food items	Farm to Retail	Retail	Household Non-edible	Household Uneaten Food	Household Cooking Yield Factor
DAIRY and EGGS					
Butter, regular	-	6	-	35	-
Cheese, hard	-	6	-	11	-
Egg, raw	-	12	12	11	9
Milk, partly skimmed	-	12	-	20	-
SPICES and HERBS					
Salt, table	-	-	-	-	-
FATS and OILS					
Vegetable oil, olive	-	21	-	15	-
Vegetable oil, canola	-	21	-	15	-
Margarine	-	7	-	35	-
POULTRY					
Chicken, roasted	40	4	-	15	30
MIXED MEAT					
Pepperoni, pork, beef	42*	4	-	1	5
CEREALS					
Cereal, ready to eat	75	6	-	4	-
Hot, oats	-	12	-	14	-
FRUITS					
Oranges, raw	5	9	27	35	-
Grapes, raw	8	9	5	35	-
Apples, raw	5	9	10	20	-
Bananas, raw	5	9	5	13	-
Melon, at farm	8	17	48	13	-
Pear, at farm	5	17	10	20	-
Strawberry	8	9	5	35	-
FRUITS JUICE					
Apple Juice	27	6	-	10	-
Grape Juice	19	6	-	10	-
Orange Juice	35	6	-	10	-
PORK					
Pork, roasted	27	4	-	1	28
VEGETABLES					
Lettuce_greenhouse, raw	7	9	5	25	-
Tomatoes, sauce, canned	59	6	-	25	-
Onions, raw	7	10	10	25	
Broccoli, boiled	7	12	39	12	plus x1.1
Carrot, raw	4	5	11	33	10
Cauliflower, raw	7	14	61	8	-
Pepper, raw	7	8	18	39	-
Potatoes, boiled	4	6	25	16	-
Tomato_greenhouse	7	10	9	8	-
VEGETABLE JUICE					
tomato juice, canned	59	6	-	10	-

Commonly Consumed Food items	Farm to Retail	Retail	Household Non-edible	Household Uneaten Food	Household Cooking Yield Factor
NUTS and SEEDS					
Almonds, dried	-	6	-	21	-
Walnuts, dried	-	6	-	18	-
Cashew	-	6	-	20	-
BEEF					
Beef, medium, pan fried	56	4	-	1	30
BEVERAGES*					
Carbonated drinks, cola	-	-	-	-	-
Tea, brewed	-	-	-	-	-
Coffee, brewed	-	-	-	-	-
Beer	-	-	-	-	-
FISH					
salmon, canned	-	6	-	17	-
tuna, canned	-	6	-	17	-
LEGUMES					
peanut butter	-	6	-	4	-
peas, green, boiled	-	6	-	10	plus x3.55
beans, snap, canned	40	6	-	24	-
soy beans, boiled	72*	6	-	10	-
tofu, fried	2*	6**	-	10**	-
split peas	-	6	-	10	plus 2.5
BAKED PRODUCTS					
bread, white	plus x1.43*	12	-	20	-
SWEETS					
sugars, granulated	86*	11	-	34	-
GRAINS					
rice, long, cooked	-	12	-	33	plus x2.6
FLOUR					
wheat flour, white	20*	12	-	20	
PASTA					
spaghetti, cooked	25*	12	-	33	plus x2.1
SNACKS					
potato chips, plain	75	6	-	4	-

Appendix B

This section provides the results of CF and CF contribution of each dietary pattern.

Table B1. 10-year change in CF contribution of annual actual and nutritionally-balanced No Pork dietary pattern

Canada's Food Guide Categories	Actual Food Basket: 2004 CF (kg CO_2 eq./person/year)	Actual Food Basket: 2015 CF (kg CO_2 eq./person/year)	Actual Food Basket: 10-Year Change in CF %	Nutritionally-Balanced Food Basket: 2004 CF (kg CO_2 eq./person/year)	Nutritionally-Balanced Food Basket: 2015 CF (kg CO_2 eq./person/year)	Nutritionally-Balanced Food Basket: 10-Year Change in CF %
Grand Total	**3225**	**2316**	**-28%**	**2331**	**1889**	**-19%**
Meat & Alternatives	**2251**	**1486**	**-34%**	**1180**	**834**	**-29%**
Meat Products	**2240**	**1468**	**-34%**	**1171**	**806**	**-31%**
Beef	1907	1339	-30%	954	666	-30%
Chicken	57	33	-42%	29	22	-24%
Fish	77	67	-13%	93	93	0%
Egg	199	28	-86%	95	25	-74%
Nuts & Seeds	**7**	**14**	**106%**	**5**	**20**	**286%**
Almonds	**0**	**7**	**-**	**0**	**10**	**-**
Legumes	**0**	**0**	**-34%**	**0**	**0**	**-29%**
Fruit and Vegetable	**314**	**296**	**-6%**	**348**	**313**	**-10%**
Vegetables	**222**	**229**	**3%**	**241**	**226**	**-6%**
Tomato sauce	0	108	-	0	72	-
Tomato	90	64	-29%	121	54	-56%
Lettuce	102	29	-71%	64	14	-77%
Potato	0	15	-	0	16	-
Onion	23	6	-73%	31	20	-33%
Pepper	0	5	-	0	6	-
Carrot	8	2	-75%	10	14	32%
Broccoli	0	0	-	15	30	100%
Fruits	**46**	**44**	**-4%**	**64**	**58**	**-9%**
Fruit Juices	**46**	**23**	**-49%**	**44**	**29**	**-35%**
Milk & Alternative	**104**	**179**	**72%**	**318**	**319**	**0%**
Beverages	**77**	**103**	**33%**	**46**	**67**	**46%**
Grains & Alternatives	**91**	**85**	**-7%**	**197**	**222**	**12%**
Others	**80**	**80**	**0%**	**80**	**80**	**0%**
Fats & Oils	**289**	**67**	**-77%**	**148**	**45**	**-69%**
Snacks	**11**	**12**	**13%**	**11**	**6**	**-44%**
Sweets	**8**	**9**	**18%**	**3**	**3**	**0%**

Figure B1. CF contribution of 2004 and 2015 annual actual and nutritionally-balanced No Pork dietary pattern

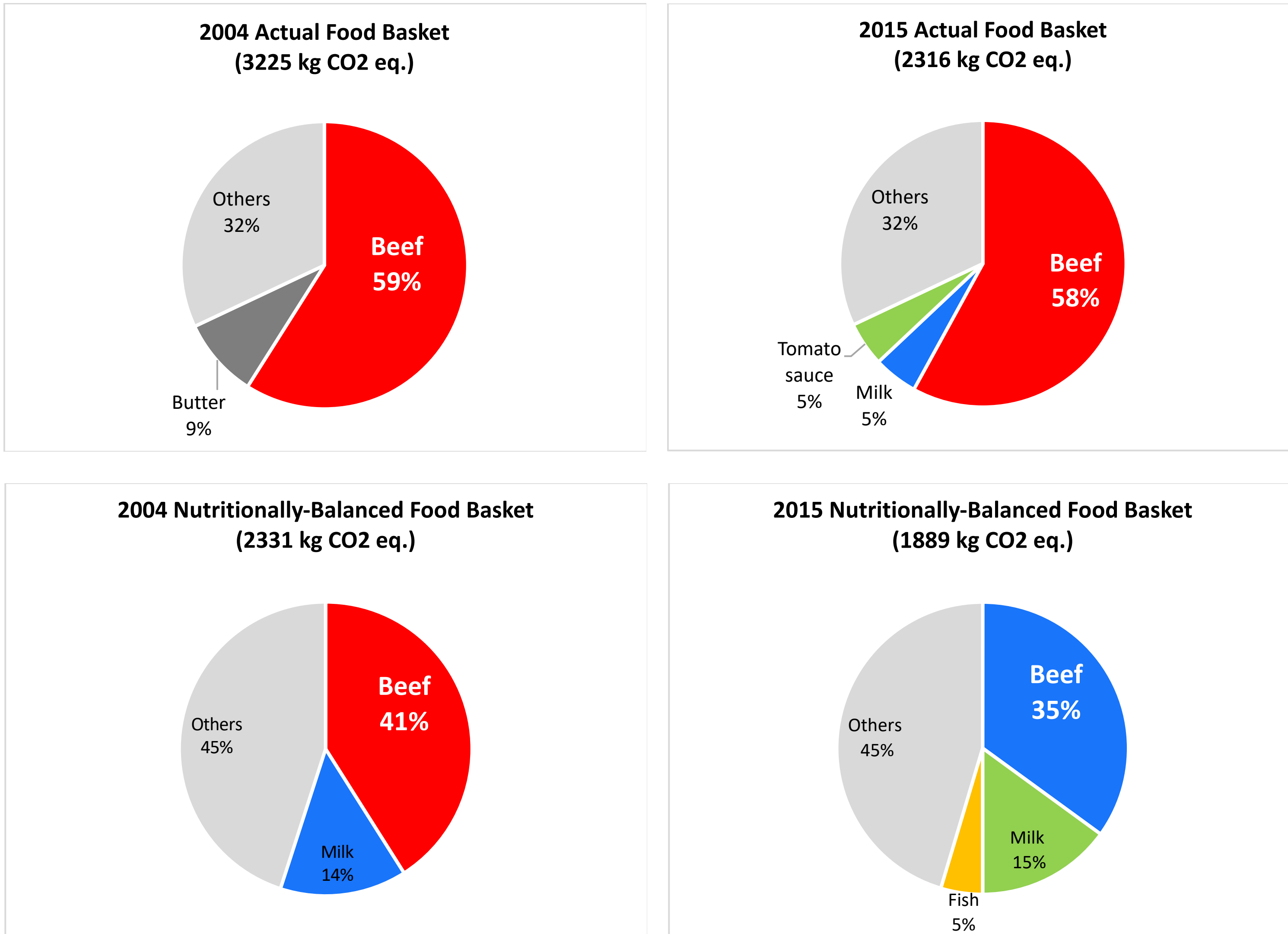

Table B2. 10-year change in CF contribution of annual actual and nutritionally-balanced No Beef dietary pattern

Canada's Food Guide Categories	Actual Food Basket: 2004 CF (kg CO_2 eq./person/year)	Actual Food Basket: 2015 CF (kg CO_2 eq./person/year)	Actual Food Basket: 10-Year Change in CF %	Nutritionally-Balanced Food Basket: 2004 CF (kg CO_2 eq./person/year)	Nutritionally-Balanced Food Basket: 2015 CF (kg CO_2 eq./person/year)	Nutritionally-Balanced Food Basket: 10-Year Change in CF %
Grand Total	1570	1248	-21%	1419	1311	-8%
Meat & Alternatives	538	405	-25%	328	264	-20%
Meat Products	312	322	3%	217	212	-2%
Pork	164	171	4%	81	85	5%
Chicken	60	56	-8%	30	32	9%
Fish	88	95	9%	106	94	-11%
Egg	213	68	-68%	95	25	-74%
Nuts & Seeds	10	10	4%	10	20	106%
Legumes	4	4	17%	6	8	29%
Vegetables & Fruits	322	247	-23%	367	283	-23%
Vegetables	226	179	-21%	257	202	-21%
Tomato sauce	-	77	-	-	53	-
Tomato	90	51	-43%	139	42	-70%
Lettuce	107	24	-77%	64	14	-77%
Potato	-	15	-	-	22	-
Pepper	-	5	-	-	6	-
Onion	20	3	-84%	28	20	-27%
Broccoli	-	-	-	15	30	100%
Carrot	8	3	-61%	10	14	38%
Fruits	49	49	0%	65	53	-19%
Fruit Juices	48	19	-61%	45	29	-36%
Milk & Alternative	97	215	122%	318	318	0%
Cheese	-	75	-	-	37	-
Milk	97	141	45%	318	281	-12%
Grains & Alternatives	103	96	-6%	199	234	18%
Beverages	73	95	31%	46	67	46%
Fats & Oils	338	94	-72%	117	57	-51%
Others	80	77	-4%	80	79	-1%
Snacks	10	12	17%	10	6	-40%
Sweets	9	8	-14%	4	3	-34%

Figure B2. CF contribution of 2004 and 2015 annual actual and nutritionally-balanced No Beef dietary pattern

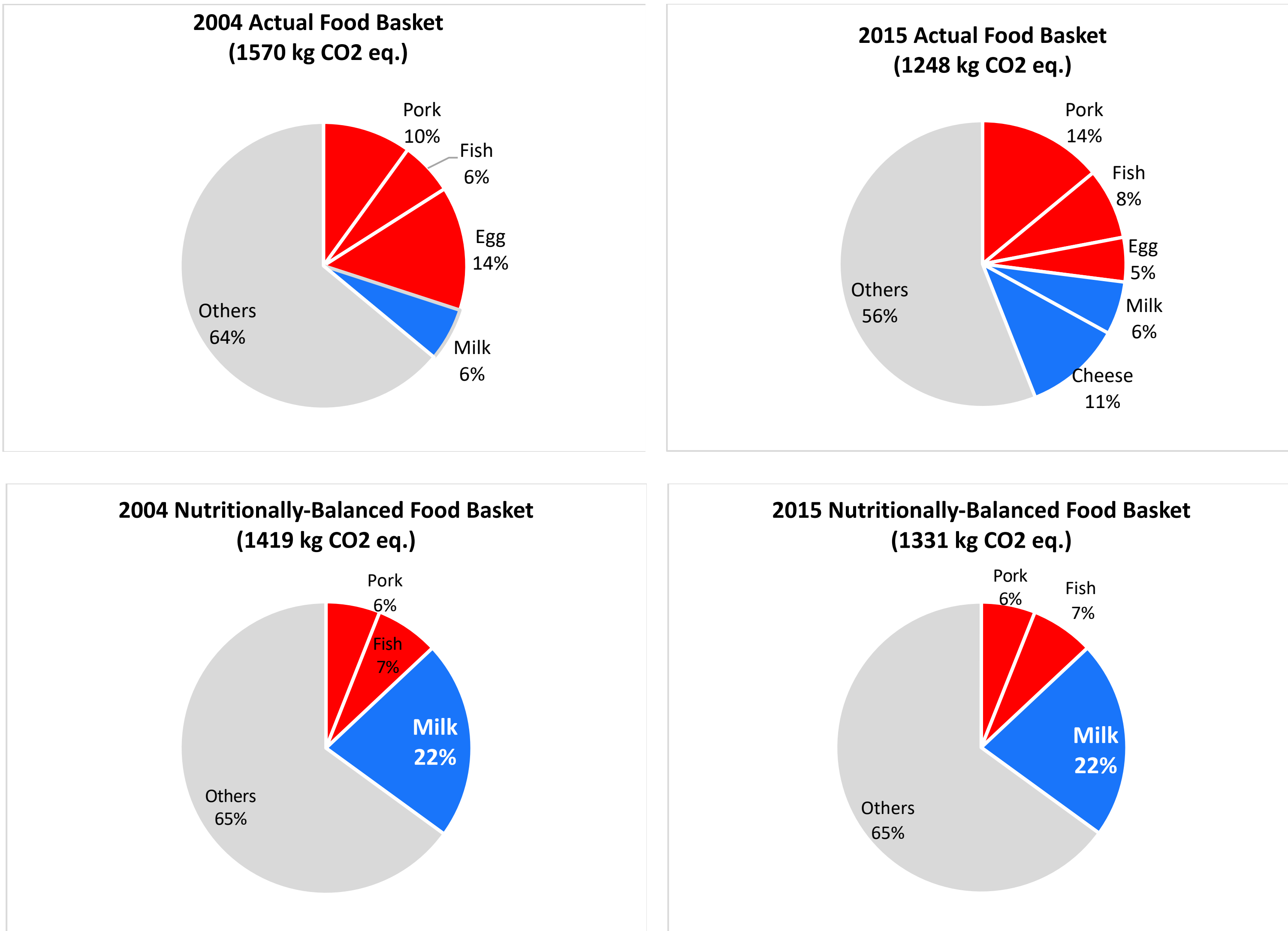

Table B3. 10-year change in CF contribution of annual actual and nutritionally-balanced Pescatarian dietary pattern

	Actual Food Basket			Nutritionally-Balanced Food Basket		
Canada's Food Guide Categories	**2004 CF (kg CO_2 eq./person/year)**	**2015 CF (kg CO_2 eq./person/year)**	**10-Year Change in CF %**	**2004 CF (kg CO_2 eq./person/year)**	**2015 CF (kg CO_2 eq./person/year)**	**10-Year Change in CF %**
Grand Total	**1534**	**1376**	**-10%**	**1457**	**1474**	1%
Meat & Alternatives	**542**	**725**	**34%**	**292**	**440**	**51%**
Meat Products	**379**	**653**	**72%**	**189**	**367**	**383%**
Fish	379	653	72%	189	367	383%
Egg	140	37	-74%	69	36	-49%
Nuts & Seeds	**18**	**15**	**-15%**	**18**	**30**	**67%**
Legumes	**6**	**20**	**236%**	**16**	**8**	**-50%**
Vegetables & Fruits	**357**	**190**	**-47%**	**410**	**284**	**-31%**
Vegetables	**242**	**128**	**-47%**	**278**	**200**	**-28%**
Tomato sauce	0	47		0	53	
Tomato	108	44	-59%	164	42	-75%
Potato	0	19		0	28	
Lettuce	111	9	-92%	64	19	-69%
Broccoli	0	6		15	25	68%
Carrot	7	1	-82%	10	13	28%
Onion	16	1	-92%	25	20	-18%
Fruits	**59**	**53**	**-11%**	**84**	**56**	**-33%**
Fruit Juices	**56**	**9**	**-84%**	**48**	**28**	**-43%**
Milk & Alternative	**200**	**131**	**-34%**	**303**	**324**	**7%**
Beverages	**58**	**91**	**58%**	**54**	**56**	**4%**
Grains & Alternatives	**85**	**88**	**3%**	**194**	**237**	**22%**
Others	**79**	**79**	**0%**	**79**	**80**	**0%**
Fats & Oils	**199**	**59**	**-71%**	**114**	**47**	**-59%**
Snacks	**7**	**7**	**2%**	**7**	**4**	**-49%**
Sweets	**6**	**7**	**15%**	**3**	**3**	**-22%**

Figure B3. CF contribution of 2004 and 2015 annual actual and nutritionally-balanced Pescatarian dietary pattern

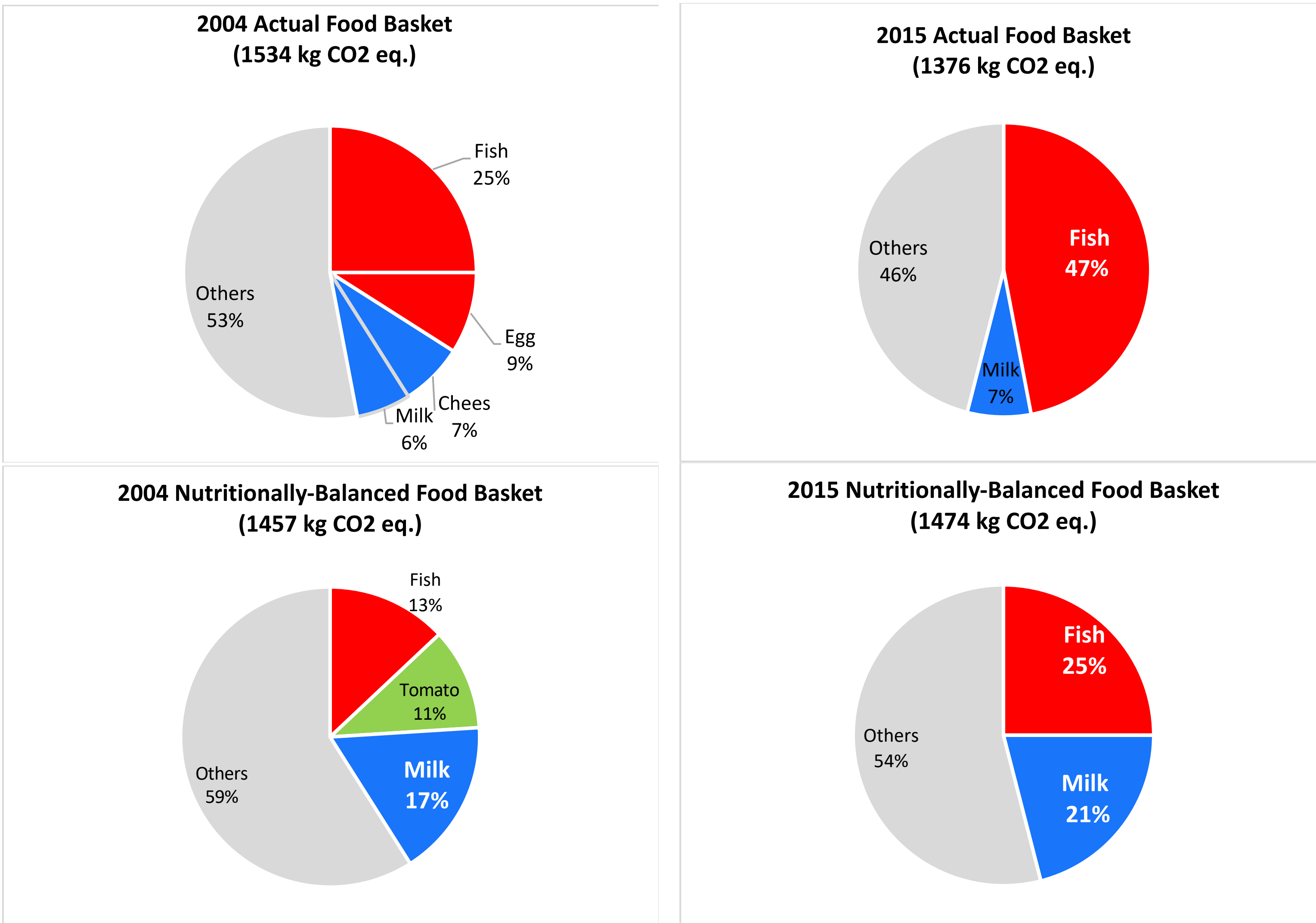

Table B4. 10-year change in CF of annual actual and nutritionally-balanced Vegan dietary pattern

Canada's Food Guide Categories	Actual Food Basket: 2004 CF (kg CO_2 eq./person/year)	Actual Food Basket: 2015 CF (kg CO_2 eq./person/year)	Actual Food Basket: 10-Year Change in CF %	Nutritionally-Balanced Food Basket: 2004 CF (kg CO_2 eq./person/year)	Nutritionally-Balanced Food Basket: 2015 CF (kg CO_2 eq./person/year)	Nutritionally-Balanced Food Basket: 10-Year Change in CF %
Grand Total	**818**	**660**	**-19%**	**931**	**825**	**-11%**
Vegetable and Fruits	**458**	**272**	**-41%**	**461**	**322**	**-30%**
Vegetables	**84**	**172**	**105%**	**173**	**223**	**29%**
Tomato sauce	14	65	367%	14	59	330%
Tomato raw	13	58	344%	39	36	-9%
Lettuce	16	30	79%	36	22	-40%
Potato	2	8	325%	2	37	1969%
Pepper	9	7	-25%	9	7	-24%
Onion	2	3	51%	6	20	246%
Broccoli	3	-	-	21	26	23%
Cabbage	2	-	-	5	-	-
Carrot	2	1	-2%	16	16	1%
Cauliflower	4	-	-	5	-	-
Zucchini	2	-	-	5	-	-
Olives	15	-	-	15	-	-
Fruits	**334**	**75**	**-78%**	**249**	**66**	**-73%**
Orange	31	27	-13%	36	24	-34%
Banana	5	18	260%	6	11	94%
Apple	3	11	257%	7	16	120%
Grape	21	11	-48%	25	7	-73%
Strawberry	5	4	-34%	7	4	-52%
Melon	8	3	-60%	14	4	-67%
Papaya	238	-	-	137	-	-
Pear	4	-	-	6	-	-
Pineapple	18	-	-	10	-	-
Fruit Juices	**39**	**13**	**-66%**	**39**	**29**	**-27%**
Grains & Alternatives	**103**	**144**	**39%**	**227**	**245**	**8%**
Bread	-	62	-	37	51	38%
Rice	32	36	12%	62	75	21%
Pasta	5	24	384%	36	65	78%
Wheat Flour	27	13	-50%	27	8	-70%
Oatmeal	7	4	-39%	7	44	506%
Cereal, ready to eat	12	4	-66%	13	2	-86%
Toasted Bread	21	-	-	44	-	-
Beverages	**120**	**45**	**-63%**	**66**	**28**	**-57%**
Others	**79**	**79**	**0%**	**79**	**80**	**0%**
Meat Alternatives	**41**	**42**	**2%**	**58**	**86**	**48%**
Fats & Oils	**11**	**22**	**102%**	**33**	**22**	**-33%**
Sweets	**6**	**13**	**134%**	**6**	**4**	**-29%**
Snacks	**1**	**10**	**1149%**	**1**	**5**	**525%**

Figure B4. CF contribution of 2004 and 2015 annual actual and nutritionally-balanced Vegan dietary pattern