Carbon Footprinting Dietary Choices in Ontario: A life cycle approach to assessing sustainable, healthy & socially acceptable diets

by
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Author 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 revision, as accepted by my examiners.

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

Anastasia Veeramani

Statistics Canada Disclaimer

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Abstract

Recent studies have established the link between food consumption and its broad impact on the environment. However, environmental implications of dietary choices have not been previously studied in Canada. Given geographic variations of eating habits and environmental impacts, this study aims to explore current dietary patterns and their environmental implications in Ontario.

This exploratory study assesses the environmental impact of seven dietary patterns and investigates the role of nutrition and dietary guidelines in evaluating sustainability of diets. Food baskets representing each dietary pattern were formed based on data obtained from dietary recall survey. Using Life Cycle Assessment (LCA), greenhouse gas emissions were estimated for farm operations, processing, distribution and household processes associated with current food consumption. Canada's dietary guidelines were used to assess the nutritional quality of current diets and propose nutritionally optimal dietary changes.

Results showed that Ontario population overconsumes protein. Popular dietary patterns including foods rich in animal protein exhibit the highest impact.

This interdisciplinary approach helps combine nutritional and environmental research which can facilitate the formulation of environmentally friendly, healthy and socially acceptable diets. The study outlines key limitations in diet-related LCA, provides recommendations for improvement and serves as a primer for further diet-related research in Canada.

Key words

Carbon footprinting, life cycle assessment, dietary patterns, nutrition, greenhouse gas emissions, dietary guidelines

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List of Abbreviations

GHG – greenhouse gases

CO_2-eq. – carbon dioxide equivalents

GWP – Global Warming Potential

LCA – Life cycle assessment

H&S – healthy and sustainable

ON - Ontario

WHO – World Health Organization

FAO - Food and Agriculture Organization of the United Nations

USDA – Unites States Department of Agriculture

UN – United Nations organization

NCDs - non-communicable diseases

Chapter 1. Introduction

"People who want to make their own contribution in the fight against climate change usually concentrate their efforts on reducing emissions in the transport sector, often ignoring that appropriately changing their eating habits could reduce their emissions to an even greater extent".

Dr. Rajendra Pachauri,
Former chair of the Intergovernmental Panel on Climate Change

1. Introduction

The global food system has been experiencing a number of challenges for the past few decades. Climate change along with food security has been at the top of many countries' agenda (European Commission, n.d.; WSFS, 2009). The population boom and rising incomes more than doubled global food consumption over the past four decades (Harrison et al., 2002). Global food production is projected to grow by 60% to meet the needs of rising population by 2050 (UN, 2014). This is creating additional pressure on the food systems worldwide (Weis, 2013). In a race to meet the rising demand, political and economic leaders, as well as policymakers often overlook the environmental repercussions of their decision-making.

Natural disasters, rising temperatures and other symptoms of climate change increasingly affect food production and security (FAO, 2008). These phenomena occur at planetary scale and affect nations worldwide. Around 30% of anthropogenic climate change and land use is linked to the dietary choices and the food system (Macrae, Cuddeford, Young, & Matsubuchi-Shaw, 2013; van Dooren et al., 2014). Modern society's dietary choices have a tremendous impact on the environment, health, and food security. Yet, these interactions are often overlooked in environmental research (Eshel & Martin, 2006).

Development and expansion of agriculture are intrinsically linked to dietary choices and contribute to deforestation, degradation of land, biodiversity loss, extensive freshwater use and water pollution (Foley et al., 2011). An estimated 30 to 50% of anthropogenic greenhouse gas (GHG) emissions are attributed to various agricultural activities (Buttriss, 2013). Agriculture, as a part of the food chain, accounts for 70-80% of the human freshwater use. Agricultural land occupies an estimated 38% of the Earth terrestrial surface (Foley et al., 2011), thus the land use

presents a significant concern. Livestock production has been shown to be one of the primary causes of overgrazing, soil erosion, desertification and tropical deforestation, to name a few (Heller & Keoleian, 2003). Pesticide use in agriculture is linked to human health impacts, groundwater contamination, pollination and crop losses, while agricultural runoff of limiting nutrients is the primary cause of eutrophication and ecosystem deterioration (Heller & Keoleian, 2003). Thus there is tremendous potential for shifts in individuals' and society's dietary choices to ameliorate these impacts (Eshel & Martin, 2006).

In addition to a diversity of environmental challenges, there is also an emerging recognition of the importance of nutrition in ensuring food security and sustainable food consumption. There is a call for nutritional sustainability, a formulation of a healthy and sustainable (H&S) diet, and a new platform for sustainable food production and consumption (FAO, 2010b). It is also vital to address the increasing number of health implications related to dietary choices. A growing body of research looking at sustainable diets incorporates nutrition quality assessment and aims at the reduction of non-communicable diseases (NCDs) (Baroni et al., 2007). The UN has recently placed the prevention of nutrition-related NCDs on the global agenda with the major focus on diet improvement (Beaglehole et al., 2011). This makes nutritional security an important component in achieving the UN Millennium Development Goals, particularly elimination of hunger, and achievement of health equity and human security.

It is essential to promote a multifaceted perspective of individual's diet, in order to shape dietary patterns that are healthy and economically, socially and environmentally sustainable. Thus, the primary goal of this research is to understand the environmental impacts of dietary patterns and establish links between nutritional and environmental components in sustainability assessment of food consumption.

1.1 Thesis structure

The present chapter provides the background information to this study, regarding the food system in Canada, and particularly in the province of interest. It presents an overview of the literature and the current state of knowledge in the assessment of diet-related environmental impacts. Research question and specific objectives conclude the first chapter of the thesis.

Chapter 2 provides a detailed description of the methodology that was used to answer the key research question and meet study objectives.

Chapter 3 presents the study results and compares them to the trends in current diet-related research. It illustrates the dietary patterns in Ontario and their nutritional status. It demonstrates the environmental impact and impact reduction potentials associated with the current consumption patterns in Ontario.

Chapter 4 focuses on the key findings that have emerged from the study results, explains the main factors that affect the validity of results and identifies opportunities for improving and applying the study results. Conclusion of the chapter contains recommendations for policy-makers, businesses and consumers as well as outlines the scope for further research.

2. Background

2.1 Environmental research of the food sector

Environmental impacts vary geographically and their magnitude is influenced by land topography, wind regimes, sun exposure, soil type, proximity to water and climate (Alber et al., 2003; Jungbluth, Tietje, & Scholz, 2000; Macrae et al., 2013; Notarnicola, 2015; Stadig, 1998). Local agriculture, assortment of available foodstuff also differs from region to region. Moreover, traditional national diets or diets that are typical to a particular location may be significantly distinct from mainstream aggregated diets.

Geographically-specific research can facilitate an accurate assessment of the environmental implications of food consumption and provide a reference point for location-specific environmental policies and action plans. Thus, it is essential to focus on regions and conduct a region-by-region analysis.

The awareness of environmental pressures created by the agricultural practices, food production and consumption, has risen in the past decade, primarily in Europe. The first studies evaluating the food consumption patterns and their effect on the environment came out in the late 1990s. Pioneers in diet-related research were Sweden (Carlsson-Kanyama, 1998; Carlsson-Kanyama, Ekström, & Shanahan, 2003; Davis, Sonesson, Baumgartner, & Nemecek, 2010; Sonesson, Mattsson, Nybrant, & Ohlsson, 2005; Wallén, Brandt, & Wennersten, 2004), the Netherlands (Kramer, Moll, Nonhebel, & Wilting, 1999), Switzerland (Jungbluth et al., 2000), with other countries such as Italy (Baroni et al., 2007; Sanfilippo, Raimondi, Ruggeri, & Fino, 2012), Spain (Davis et al., 2010; Muñoz, Milà i Canals, & Fernández-Alba, 2010), Finland (Risku-Norja et al., 2009; Saarinen et al., 2012; Virtanen et al., 2011), Romania (Vintilă, 2010),

Denmark (Saxe, Larsen, & Mogensen, 2013), Austria (Fazeni & Steinmüller, 2011), UK (Berners-Lee, Hoolohan, Cammack, & Hewitt, 2012; Collins & Fairchild, 2007; Macdiarmid et al., 2012), France (Vieux, Darmon, Touazi, & Soler, 2012; Florent Vieux, Soler, Touazi, & Darmon, 2013), and Germany (Meier & Christen, 2012a, 2012b) joining the initiative and adopting similar diet-related research frameworks.

Relatively fewer countries outside Europe are conducting research of a similar nature, including USA (Weber & Matthews, 2008), India (Pathak, Jain, Bhatia, Patel, & Aggarwal, 2010), China (Chen, Gao, Chen, & Zhang, 2010), Australia (Friel, Barosh, & Lawrence, 2013; Hendrie, Ridoutt, Wiedmann, & Noakes, 2014) and New Zealand (Wilson et al., 2013). Recently, research has been initiated to determine the environmental footprint of global food consumption (Schmidt & Merciai, 2014). Overall, there seems to be a lack of comprehensive research aimed at studying the life cycle environmental footprint of food consumption and realistic dietary patterns in Canada.

In Canada, research work related to the environmental repercussions of food consumption is nascent and very limited. Kissinger (Kissinger, 2013) estimated the overall ecological footprint of Canadian food consumption, but did not differentiate between the various food consumption patterns across the country. A few studies have also evaluated the food miles associated with the total Canadian imports (Kissinger, 2012), key food imports to Kingston region, Ontario (Lam, 2007) and Nova Scotia (Scott & MacLeod, 2010) and a food basket in the Region of Waterloo, Ontario (Xuereb, 2005). Although, the food miles related research gives perspective on the transport-related emissions of food sector, it focuses purely on the greenhouse gas emissions and is limited to only one source of emissions (i.e. freight).

Macrae and coworkers (Macrae et al., 2013) analyzed food-related GHG emissions in Canada and investigated the climate change potential reductions from the country's food sector. The researchers compared the GHG emissions associated with various modes of transportation, some food products, local and foreign production, local field- and greenhouse-grown and imported products as well as organic and conventional production.

There is a growing body of research on the environmental footprinting of single agricultural products in Canada. It has covered the environmental footprint of dairy products (McGeough et al., 2012; O'Brien et al., 2012), beef (Beauchemin, Janzen, Little, McAllister, & McGinn, 2011; Dias et al., 2015), salmon (Ayer & Tyedmers, 2009), wine (Point, Tyedmers, & Naugler, 2012), apples (Keyes, Tyedmers, & Beazley, 2015), greenhouse tomatoes, cucumbers, lettuce and

peppers (Dyer, Desjardins, Karimi-Zindashty, & McConkey, 2011). However, the single product analysis provides very little insight into the overall impact associated with the food consumption in Canada and environmental implications of a Canadian diet as a whole are not well studied (Macrae et al., 2013).

2.2 Canadian food sector

The food system presents a great opportunity for climate change mitigation in Canada (Macrae et al., 2013). Canada is one of the largest producers and exporters of agricultural products globally. The country is in the top seven largest producers of wheat, pork and soybeans (Grant, Bassett, Stewart, & Adès, 2011).

Over 70% of all the food sold in Canada is produced domestically; for meat and dairy as well as breads and cereals these estimates are higher (80% and 76%) (Statistics Canada, 2012). Despite large volumes of local production, the country heavily relies on the food import with 15% of meat, 17% of legumes, 35% of oils, 40% of fish, 80% fruit and 45% of vegetables being produced abroad (Kissinger, 2012; Statistics Canada, 2012).

The food sector in Canada is a vital economic driver, contributing over 9% to the national GDP and 13% to overall employment (Grant et al., 2011). Food and beverage manufacturing has been, and remains, the leading branch in the Canadian food system (Grant et al., 2011). Agriculture, being a primary sector, is also a significant part of the Canadian food system with a large scope for expansion. Seventy percent of land in Canada is arable, while only 7% is used for agriculture (Statistics Canada, 2009).

However, expanding food sector puts increasing pressure on the environment. Agricultural practices affect the wildlife habitat, soil and water quality among others. Nutrient management and pesticide application pose a great risk of nutrient runoff and water contamination (Statistics Canada, 2009). Meanwhile, the farmland affected by the fertilizer use and herbicide application increased by up to 400 and 200% since 1970s (Statistics Canada, 2009).

Agriculture and food production are also heavily dependent on water. According to Statistics Canada (2009), water use in Canadian agriculture reached an estimated 4.8 billion cubic meters, 92% of which was attributed to irrigation. Water intake in the food manufacturing accounted for over 26% of total water use in the manufacturing sector, or 3.5% of the total water consumption in Canada (Statistics Canada, 2009).

Greenhouse gases from agriculture have increased by over 25% since the early 1990s (Statistics Canada, 2009). In 2006, Canada's agriculture produced over 62 Mt CO_2-eq., or over 8.6% of total GHG emissions (Environment Canada, 2015; Statistics Canada, 2009). These values present substantial evidence that the agriculture and food production notably contribute to the increasing environmental pressures and present a great opportunity to alleviate them.

2.2.1 Ontario context

Ontario is the second largest and the most populated province in Canada, with its 13,678,740 residents accounting for around 40% of total population (MOF, 2015). Its food and beverage manufacturing sector is the largest in the country (40% of total food manufacturing) and the third largest in North America (FBO, 2015; OMARFA, n.d.).

The agriculture and food sector in Ontario plays a significant part in the province's development and economic growth. The food system secures employment for more than 740,000 Ontario residents and contributes over $34 billion to the province's economy, or over 6% of its GDP (Grant et al., 2011; Ontario Government, 2013c). The agriculture and food sector also sets an ambitious goal of doubling its growth rate and export volumes, while creating 120,000 new jobs by 2020 (Grant et al., 2011; Ontario Government, 2013c).

Provincial and federal governments also have a strong focus on and invest in the development of the agriculture and food sector in Ontario. Financial assistance and tax incentives for Ontario's agri-food sector come from Agriculture and Agri-Food Canada, Canada Revenue Agency, Ontario Centre of Excellence, the Ontario Ministry of Agriculture and Food and the Ministry of Rural Affairs, among others (Ontario Food Cluster, 2014).

The provincial government facilitates the agri-food sector's competitiveness through innovative projects such as the Canadian Agricultural Adaptation Program (CAAP) led by Agricultural Adaptation Council; and helps the small and medium enterprises get increased access to the global markets through extensive projects such as Export Market Access, a global expansion program (Ontario Food Cluster, 2014).

Federal government programs aim to boost innovation, food safety, marketing and improve competitiveness of agri-food industry through the 'Growing Forward 2' project; and promote competitiveness and increased access to private sector investment for new enterprises through the 'Investing in Business Innovation' program (Ontario Food Cluster, 2014).

Significance of the food sector in Ontario is also supported by a strong 'local food' movement, which along with a food sovereignty initiative within Bill 36, Local Food Act 2013 (Ontario Government, 2013b), increase the relevance of investigating the local food system and its environmental impacts, with the goal of making it more sustainable and resilient.

Food-related environmental research also aligns well with other current initiatives in the province. The provincial government is aiming at establishing local healthy and sustainable food systems on regional levels ("The Sustainable Food Systems project," n.d.), reducing GHG emissions while supporting provincial economic goals within Ontario's Action Plan On Climate Change (Ontario Government, 2007), focusing on clean energy sources within the long-term energy plan (Ontario Government, 2013a), alleviating environmental pressure on air within the Air Quality Control programs (Ontario Government, n.d.) and improving the health of Ontario residents within Ontario's Action Plan for Health Care (Ontario Government, 2014). Thus, along with the strong focus on the development of the local economy, Ontario government puts great emphasis on environmental policy and the sustainability of the food system.

Another distinct feature of the Ontario province is the diversity of population. Over three quarters of its residents come from diverse ethnic and cultural backgrounds (Ontario, 2011, n.d.). Diversity of population is likely to entail significant variations in people's dietary preferences and provincial demand for local and imported food. Identifying the key dietary patterns within the Ontario population is decisive in assessing their environmental implications associated with the local food sector.

Given the existing knowledge gap in diet-related research in Canada, current policy focus and significance of the food system in Ontario, and intricate connection of the food sector and the environment, the study aims to understand the overall impact of the Ontario food system on the environment, and particularly assess the implications of the dietary choices of Ontario population on the climate change.

3. Literature review: Life Cycle Assessment of dietary patterns

The following section presents a literature overview of diet-related research. The goal of the literature review is to demonstrate current knowledge gaps, identify current research practices as well as build the framework for further research and provide rationale for methodological decisions.

Specifically, section 3.1 of the literature review demonstrates the common practices in selecting dietary patterns for conducting further assessment of their environmental impact. Section 3.2 presents the leading method for the environmental research and presents a state of knowledge in diet-related LCA. It particularly focuses on the choice of functional unit, impact categories, system boundaries and other parameters in diet-related LCA. Lastly, section 3.3 highlights the importance of incorporating nutritional assessment in diet-related research.

3.1 Identifying dietary patterns

To obtain information on the food intake of various populations, researchers refer to food balance sheets (Berners-Lee et al., 2012), national nutrition survey data (Berners-Lee et al., 2012; van Dooren et al., 2014), household expenditure statistics (Friel et al., 2013; Muñoz et al., 2010; Saner, Stoessel, Jäggi, Juraske, & Hellweg, 2014), self-reported food intake and weekly food diaries (Berners-Lee et al., 2012; Carlsson-Kanyama et al., 2003; Hoolohan, Berners-Lee, McKinstry-West, & Hewitt, 2013; Vieux et al., 2012). Food balance sheets provide aggregated information on daily food availability per capita, and thus do not allow identifying various patterns of consumption. Dietary surveys and food diaries primarily focus on the real consumption and account for diversity in the food choices but often do not consider the food waste at an individual level. Household expenditure surveys mostly rely on the information about purchased rather than consumed products; hence the proportion of consumption and food waste remains uncertain. Moreover, the data are provided for the entire household and lack the level of detail required to identify individual consumption patterns. Some studies corroborate the findings from the dietary surveys with household budget surveys, thus making their estimates more accurate (Friel et al., 2013; Tukker et al., 2011).

Researchers also construct hypothetical diets that align well with common lifestyles and meet the nutritional guidelines (Baroni et al., 2007; Friel et al., 2013; Hendrie et al., 2014; Meier & Christen, 2012a; Risku-Norja et al., 2009; Saarinen et al., 2012; van Dooren et al., 2014). However, they often fail to reflect the typical food intake of the target population.

Some researchers also determine dietary patterns based on the socio-economic stratification in the society (Druckman & Jackson, 2009). However, this approach does not allow the reader to see the prominent differences in the food consumption between the population groups without the additional description.

3.2 Environmental footprint of food consumption

The current environmental research in the area of food production and consumption ranges from the environmental assessment of individual food items to meals and dietary patterns. The differences in the main focus of studies entails methodological issues, particularly when estimating the environmental performance of entire diets.

3.2.1 Single agricultural products

There has been extensive research on environmental footprinting of agricultural products. Their focus ranges from dairy products, meat, bread, beer, rice, sugar beet, tomato, potato to various condiments (Roy et al., 2009). In Canada food consumption-related research has covered the environmental footprint of dairy products (McGeough et al., 2012; O'Brien et al., 2012), beef (Beauchemin et al., 2011), salmon (Ayer & Tyedmers, 2009), wine (Point et al., 2012), greenhouse tomatoes (Dias et al.,2014), cucumbers, lettuce and peppers (Dyer et al., 2011) and carbon footprint of the entire national food import (Kissinger, 2012).

Based on the findings of the existing studies on the environmental implications of the food consumption, food items that consistently exhibit the highest environmental impact include red meat from cattle and sheep (Baroni et al., 2007; Carlsson-Kanyama et al., 2003; Carlsson-Kanyama & González, 2009; Goodland, 1997; Hendrie et al., 2014; Hoolohan et al., 2013; Kramer et al., 1999; Muñoz et al., 2010; Tukker et al., 2011), dairy (Baroni et al., 2007; Kramer et al., 1999; Muñoz et al., 2010; Pathak et al., 2010; Tukker et al., 2011), fish (Baroni et al., 2007), shrimp (Carlsson-Kanyama et al., 2003) and rice (Carlsson-Kanyama & González, 2009; Pathak et al., 2010), among others. Food items that predominantly have a relatively smaller environmental footprint are white meat (Carlsson-Kanyama & González, 2009; Jungbluth et al., 2000) and some exotic, geographically specific meat such as kangaroo (Friel et al., 2013), fresh vegetables (Berners-Lee et al., 2012; Carlsson-Kanyama & González, 2009), grains (Carlsson-Kanyama & González, 2009; Goodland, 1997) and legumes (Carlsson-Kanyama et al., 2003; Carlsson-Kanyama & González, 2009; Davis et al., 2010; Hendrie et al., 2014).

The environmental performance of these food items was assessed from the perspective of both the full life cycle (Muñoz et al., 2010) and particular life cycle phases (Saxe et al., 2013). It was also evaluated in terms of a single impact category such as the carbon footprint (Carlsson-Kanyama & González, 2009) and a wide spectrum of impact categories such as ecotoxicity,

water and land use, acidification, eutrophication and other (Baroni et al., 2007). The environmental performance of these food items varies according to geographic locations, but reveals similar trends.

Despite the consistency among existing studies with regard to grouping high- and low-impact food groups, the impact indicators still differ in various regions. Given that environmental impacts are highly dependent on the existing environment in the geographic location, the environmental performance of the food categories and single items will likely vary in countries with diverse climates such as Canada.

Studies on the life cycle of single food items help build the database for food-related research. Singling out the hotspot ingredients in diets is considered crucial and lays foundation for transforming the diets (Baroni et al., 2007). The data on the environmental performance of single food items also help highlighting the areas of potential improvement in agricultural practices and in the food supply chain in general, and guiding consumer food choices.

In terms of the application of such databases in diet-related research, accumulation of data on single food products would facilitate the bottom-up approach to assessing the environmental impacts of full diets. Continuous development and update of these databases will require time and resources for their accumulation but it will also allow easy access to the data, better data quality and faster turnaround of the life cycle assessment studies. However, the application of the database requires consistency in the model assumptions, system boundaries, impact categories, allocation methods, functional units and other parameters. On the large scale, it might be an obstacle to producing a transparent, accurate and consistent database due to a number of other uncertainties and potential data gaps, and challenges with allocation methods that might not be universal for all the food types.

3.2.2 Aggregated meals and diets

Aggregating food in the meals and diets provides a more appropriate basis for studying environmental footprint of food consumption, because they represent the true consumption patterns (Heller, Keoleian, & Willett, 2013). Although meals (Virtanen et al., 2011) demonstrate a realistic food intake such as breakfast, lunch or dinner, they might not represent a comprehensive dietary pattern as well as a full diet. The food basket is a set of food items representing typical food intake on a weekly, monthly or annual basis. It is another common method to reflect food consumption. It can also be used as a unit to express the composition of

various diets and food choices (Friel et al., 2013; Pretty, Ball, Lang, & Morison, 2005; Tukker et al., 2011).

More than a decade ago, there was no agreement on the importance of diet in sustainable agricultural development (Goodland, 1997). However, currently there is a general consensus that contribution of food consumption and dietary patterns has a tangible impact. This indicates the starting point for increasing research on diets.

Diets can be aggregated on a national scale or individual level. Thus, various studies approach the process of environmental assessment of diets on different levels. Some researchers use national averages to compose the national diet, often analyzing the national availability statistics and food balance sheets (Tukker et al., 2011) or national agricultural production inventories (Jungbluth et al., 2000). This approach is likely to be predetermined by the availability of data, scope of the study or intended application of the findings. Other researchers gather information about individually specific diets by collecting food intake self-reports or surveys of individuals and households (Coley, Goodliffe, & Jennie, 1998; Hoolohan et al., 2013; Vieux et al., 2012; Vieux et al., 2013). There are also studies that combine different approaches and develop the diet patterns based on a combination of above-mentioned sources (Berners-Lee et al., 2012; Carlsson-Kanyama et al., 2003; Meier & Christen, 2012a). The collection of individually reported food intake data represents more realistic dietary patterns, helps reduce the level of aggregation and increase the level of precision. However, given the sheer amount and variety of food items being reported, the processing of the collected data for the purpose of the environmental analysis is likely to result in aggregated food items within food groups. Thus, the method of analysis itself might reduce the accuracy of such approach.

In the analysis of diet composition, researchers encounter a great variety of dietary patterns. Two major diet groups are animal-based and plant based diets. As a general trend, similar to the environmental performance of individual food items, animal-based diets have shown a larger environmental burden than plant-based diets in terms of GHG emissions (Berners-Lee et al., 2012; Eshel & Martin, 2006; Hendrie et al., 2014; Pathak et al., 2010; Saxe et al., 2013; Tukker et al., 2011) and other impact categories (Baroni et al., 2007) . Lacto-ovo vegetarian diet, a variation of animal-based diets, also exhibited higher environmental impacts than purely plant-based diet, due to consumption of dairy products, but is still considered preferable to other diets including meat (Berners-Lee et al., 2012; Meier & Christen, 2012a; Pathak et al., 2010). Important factors which may affect the outcome of environmental assessment of animal-based diets and need to be

considered include the balance and share of meat, fish and dairy products and other food items in the diet, the type of meat consumed, the frequency of consumption and the livestock production practices employed in the region of analysis. Thus, precise dietary composition can better reflect the true environmental implications of a diet and help prevent misleading generalizations.

Plant-based diets are believed to have a relatively smaller overall impact (Baroni et al., 2007; Meier & Christen, 2012a; Risku-Norja et al., 2009; van Dooren et al., 2014). Plant-based diets, by definition, are richer in fruit and vegetables, nuts and seeds and legumes. A number of studies encourage shifting towards higher consumption of alternative sources of protein such as vegetables and legumes due to their lower environmental impact and higher health benefits (Hendrie et al., 2014; van Dooren et al., 2014). However, in most cases, switching from animal-based proteins to plant-based proteins might potentially trigger higher environmental impacts due to land use change, additional irrigation, use of fertilizers and pesticides. Therefore, it is equally important to know the agricultural practices employed, the methods of production, and balance of fresh or preserved plant-food, the share of vegetables and fruit relative to grains, nuts or legumes, type of grains, fruit and vegetables.

Another factor worth considering is the share of the 'non-core' food items in the diet such as snacks, sweets, alcohol, beverages and soft drinks that are often highly processed. Diets containing large amounts of 'non-core' products have been shown to have a high environmental impact (Berners-Lee et al., 2012; Saxe et al., 2013; van Dooren et al., 2014). Thus, if a large share of these 'non-core' products is added to a low-impact vegan diet, its performance could be poorer than a fully meat-based diet.

Generally, environmental assessment of diets is based on hypothetical and realistic diets. Hypothetical diets are primarily based on the existing dietary guidelines or proposed H&S diets (Friel et al., 2013; Saxe et al., 2013); while the average diet composition is likely to show the true environmental impacts of diets, the theoretical formulation of diets provides a scope for creating scenarios of an ideal H&S diet composition.

Realistic dietary patterns based on national statistics are often compared with the recommended dietary alternatives to confirm if the 'ideal' diets are indeed healthy and sustainable, or at least, more environmentally friendly (Friel et al., 2013; Hendrie et al., 2014; Meier & Christen, 2012a; Saxe et al., 2013; van Dooren et al., 2014). Thus, the findings of these

comparative studies set the stage for developing national food strategies and programs, reconsidering national dietary guidelines or stimulating further research (Heller et al., 2013).

Considering diets as a whole provides a more realistic assessment of environmental impacts. Application of national statistics, data from economic input-output models or industry averages facilitates top-down approach to analyzing the environmental impact of dietary patterns and might be an alluring option as highly available and accessible data sources. However, due to lack of desirable level of detail, the aggregated or average values might not provide substantial data to identify dietary patterns or quantify the contribution of a particular sector, industry or life cycle phase to the overall impact. Thus, results might be misinterpreted or overestimated.

3.2.3 Methodological issues in assessing environmental implications of dietary patterns

Among the plethora of research methods employed to estimate the environmental impacts associated with various products, particularly food, LCA has become a dominant methodological framework over the past years. Around 80% of existing studies on environmental impacts of food consumption use LCA as the framework (Heller et al., 2013). Thus, a recent assessment of environmental performance of the current Italian Food Pyramid and the subsequent creation of the Double Food Pyramid was also based on an LCA approach (Ciati, Ruini, Burlingame, & Dernini, 2012). Other methods include but are not limited to the economic input-output (EIO) models (Coley et al., 1998; Duchin, 2005; Hendrie et al., 2014; Virtanen et al., 2011), carbon footprint models (Coley et al., 1998; Eshel & Martin, 2006), and to a lesser extent, frameworks estimating ecological footprint (Chen et al., 2010; Collins & Fairchild, 2007; Vintilă, 2010), land use analyses (Desjardins, MacRae, & Schumilas, 2010; Gerbens-Leenes & Nonhebel, 2002; Gerbens-Leenes, Nonhebel, & Ivens, 2002; Gerbens-Leenes & Nonhebel, 2005; Peters, Wilkins, & Fick, 2007; Zhen et al., 2010), scenario analyses (Berners-Lee et al., 2012; Erb et al., 2009; Hoolohan et al., 2013; Saxe et al., 2013; Wilson et al., 2013), integrated global environmental models (Popp, Lotze-Campen, & Bodirsky, 2010; Stehfest et al., 2009) and consequential LCA (Saxe et al., 2013).

Researchers also apply hybrid-methods to strengthen the analysis (Berners-Lee et al., 2012), such as hybrid of LCA and EIO models (Berners-Lee et al., 2012; Finnveden et al., 2009; Kramer et al., 1999; Meier & Christen, 2012a), largely due to the ability of EIO-LCA to process large amounts of food items and reduce the cut-off errors which are seen as a major drawback in process-based LCA (Weber & Matthews, 2008).

The essence of LCA is the assessment of environmental impacts that can potentially occur throughout the product's life cycle - from the raw material extraction to the end of life and waste management. The unique approach allows addressing a spectrum of various impacts associated with the production and consumption of a product. Such an overarching method is likely to provide a complete environmental profile of a product and a systematic basis for developing major environmental indicators (Heller & Keoleian, 2003).

In Canada, LCA was largely initiated by the industries including steel, aluminum, wood, plastic and paper industries; and extensively focused on packaging and solid waste (Young, 2003). However, there has been a recent increase in application of LCA for agricultural and food-related research (Ayer & Tyedmers, 2009; Dias et al., 2015; Koehler-Munro, Courchesne, Moe, Bryan, Goddard, & Kryzanowski, 2014; Mackenzie, Leinonen, Ferguson, & Kyriazakis, 2014; Moe, Koehler-Munro, Bryan, Goddard, & Kryzanowski, 2014; Vergé, Dyer, Desjardins, & Worth, 2007). It has also attracted a great interest from policy makers as a tool to assess and address environmental issues in a Canadian context (Macrae et al., 2013; Young, 2003).

3.2.3.1 Comparing diets

The LCA methodology uses a functional unit to compare environmental impacts between products and services. To choose the appropriate functional unit for comparison, the key function of a product, a process or a system has to be defined. The primary function of food consumption is to supply energy and nutrition to the body. Hence, incorporating a nutritional component in the assessment of the food consumption is crucial. A preferable functional unit would encompass various nutritional characteristics of a food item or a set of items. Given that there is currently no universal standard to account for nutritional indicators in LCA, this requirement is challenging to fulfill (Heller et al., 2013; Kendall & Brodt, 2014; Sonesson et al., 2005).

Mass- and volume-based functional units are suitable for the assessment of life cycle impacts of a single food item and comparison of food production practices (Carlsson-Kanyama et al., 2003; Coley et al., 1998; Heller et al., 2013; Jungbluth et al., 2000; Saxe et al., 2013). However, this functional unit does not reflect the nutritional function of a product, which is vital in the assessment of food consumption. To factor in the nutritional component in this functional unit, the researchers propose quality corrected mass and volume, which is a standard practice in a

number of industries. Thus, the mass of milk is adjusted by the fat and protein content (Heller et al., 2013) and bread flour is corrected by protein content in wheat (Audsley et al., 2003).

Moreover, mass- and volume-based functional units are also challenging to incorporate in the assessment of a full diet. Although knowing the components of a diet and their corresponding amounts is important, the reference to mass or volume of an aggregated diet would impede the measurement of its environmental impact and following comparison between the dietary patterns. Nevertheless, regulatory bodies such as the European Food Sustainable Consumption and Production Round Table Working Group 1 still recommend applying mass-based functional units such as 100 g or ml (De Camillis et al., 2011).

In case of analyzing processed and unprocessed products, the choice of the functional unit is one of the determinants of the results. Brodt and coworkers (Brodt, Kramer, Kendall, & Feenstra, 2013) demonstrated the difference in the analysis results produced for fresh tomatoes and tomato paste. On a mass or volume basis, the paste, as a more concentrated product, is likely to have a higher impact than the fresh produce in terms of land use but lower impact in terms of transportation (Brodt et al., 2013). Thus, serving, portion size or supply of a particular nutrient could serve as a more accurate functional unit than mass or volume (Pathak et al., 2010).

Studies on food consumption also look at time-related food intake as a functional unit. The food intake is considered on a weekly (Baroni et al., 2007; Carlsson-Kanyama et al., 2003), monthly and annual (Muñoz et al., 2010) basis. This functional unit might represent actual food choices and reflect sustainability status of a diet but hardly consider its nutritional security.

Nutrition-based functional units provide a better choice for the assessment and comparison of food items, meals and diets because they incorporate the primary function of delivering nutrition (Heller et al., 2013). Researchers widely employ the caloric value (Baroni et al., 2007; Berners-Lee et al., 2012; Coley et al., 1998; Saarinen et al., 2012; Saxe et al., 2013; Tukker et al., 2011), protein (Davis et al., 2010; González, Frostell, & Carlsson-Kanyama, 2011), carbohydrate, fat and sodium content (Berners-Lee et al., 2012; Risku-Norja et al., 2009) as a nutrition-based functional unit. For example, the studies utilizing the protein-based functional unit show that plant-based proteins have a better environmental performance in comparison with animal-based proteins (Carlsson-Kanyama & González, 2009; Davis et al., 2010; de Boer, Helms, & Aiking, 2006; González et al., 2011; Reijnders & Soret, 2003; van Dooren et al., 2014). Thus, diets rich in plant-based protein tend to have a better sustainability score. The analysis, however, is often narrowed down to a single indicator, which limits understanding of the complex nutritional

quality of a food item, a meal or a diet. Given that a nutritional indicator can be expressed in a variety of ways, emerging research incorporates variations of more comprehensive nutritional indicators such as nutrient density (Smedman, Lindmark-Månsson, Drewnowski, & Edman, 2010) or nutritional profiling (Heller et al., 2013; Saarinen, 2012) and makes an attempt to consider the whole spectrum of micro- and macro-nutrients (Hendrie et al., 2014; Pathak et al., 2010).

Despite the shortcomings and limitations of methods to incorporate nutritional value in the functional unit, and although there are still studies that use ambiguous indicators (e.g. a serving of pasta suggested by a producer or suggested in a dietary guideline) or do not consider nutritional value at all, a prevailing number of LCA studies on food consumption apply at least some nutritional indicators (Carlsson-Kanyama et al., 2003; Friel et al., 2013; Jungbluth et al., 2000; Kramer et al., 1999; Meier & Christen, 2012a). Among functional units accounting for nutritional value of food, researchers used a single meal (breakfast, lunch or dinner) (Carlsson-Kanyama et al., 2003; Davis et al., 2010; Saarinen et al., 2012; Theurl, Hörtenhuber, Theresia, Lindenthal, & Wirz, 2014; Virtanen et al., 2011), recommended daily amounts or daily energy intake (Gerbens-Leenes & Nonhebel, 2002; Hendrie et al., 2014; Meier & Christen, 2012a; van Dooren et al., 2014), weekly food plan (Baroni et al., 2007), food basket (Friel et al., 2013) and balanced annual food consumption (Muñoz et al., 2010; Risku-Norja et al., 2009; Wallén et al., 2004).

Given the other functions of food - such as providing comfort and pleasure, shaping culture and traditions, and promoting social interaction - there are also alternative functional units to reflect these. Schau and Fet (2008) suggested accounting for characteristics of food such as texture and viscosity. Dutilh and Kramer (2000) considered emotional value of food and created a matrix representing nutritional and emotional values.

Current food-related research lacks consistency in defining functional units and produces varying and often misleading estimates. Various functional units yield significantly different results, particularly in the comparative studies. Thus, Kendall and Brodt (2014) and Heller et al. (2013) demonstrated the vast difference in LCA results for an array of food items based on various functional units such as consumed mass, 'as-sold' mass, serving size, energy and protein content, as well as weighted nutrient density score. These findings corroborate the importance of choosing an appropriate functional unit.

3.2.3.2 Boundaries of Assessment

Considering the life cycle of food in its entirety may appear as a challenging and to some extent unnecessary task. The current state of research on dietary patterns indicates that only a few studies have considered the whole life cycle of food chain in order to understand its environmental implications (Davis et al., 2010; Heller & Keoleian, 2003; Muñoz et al., 2010; Schmidt & Merciai, 2014). The boundaries that are set to measure the production side of the food supply chain are often limited to 'cradle to farm gate' impacts. Studies that also factor in the distribution, storage and use stages of the life cycle are likely to be marked as 'farm to fork', 'farm to plate' or 'farm to table' (Carlsson-Kanyama et al., 2003; Carlsson-Kanyama & González, 2009; Theurl et al., 2014). Studies that consider 'cradle to store' stages conduct the analysis up to the supermarket check-out or other consumer purchase points (Berners-Lee et al., 2012; Hoolohan et al., 2013; Meier & Christen, 2012a; Saxe et al., 2013).

The pre-farm stage of the food life cycle encompasses production of fertilizers, pesticides and farm machinery. It accounts for around 40% of the energy allocated to agricultural production (Heller & Keoleian, 2003) but is not largely considered within the system boundaries of existing studies (Carlsson-Kanyama et al., 2003; Friel et al., 2013; Pathak et al., 2010).

Agricultural processes (cradle-to-farm-gate) are the primary focus in the prevailing number of studies. Agriculture contributes around 20% of the total energy use in the US food system (Heller & Keoleian, 2003). It is also responsible for around 70% of climate change impacts (Virtanen et al., 2011). Livestock production is considered a hotspot in the agricultural production of food and may account for up to 80% of agricultural GHG emissions (Friel et al., 2013). However the researchers are not limited to the agricultural production exclusively and consider other stages along the food life cycle.

The distribution stage encompasses packaging, retail storage and supermarket operations, to name a few. Current research suggests that transportation to retail locations and households accounts for around 11% of the total GHG emissions (Weber & Matthews, 2008). However, the impact largely depends on the mode of transportation and origins of the product.

Use or consumption stage of the life cycle of food includes but is not limited to household storage, preparation and food waste. Heller et al. (Heller et al., 2013) estimated that the energy consumption at the household level contributes to 32% of the total energy use of the American food system (Heller & Keoleian, 2003). Storage and cooking alone contribute around 10-14% to

the total GHG emissions (Heller et al., 2013; Muñoz et al., 2010), 23% to primary energy use (Muñoz et al., 2010) and 13-17% to total energy use (Heller et al., 2013). Consequently, they represent a considerable input to the environmental impact of a diet. Nevertheless, this essential stage of life cycle is often omitted from studies or is given a second priority (Berners-Lee et al., 2012; Friel et al., 2013; Kramer et al., 1999; Meier & Christen, 2012a; Saxe et al., 2013; Vieux et al., 2012). The primary reasons for lower inclusion of the use stage in the food-related studies are consumption data gaps and the unique nature of consumption behavior (Heller et al., 2013). While agricultural practices can be similar and thus generalizable, consumption patterns, cooking styles and storage practices may vary.

Although human excretion and waste treatment might not be an impact hotspot in regards to energy consumption, climate change, land use or biodiversity loss, this stage contributes around 17% to the overall eutrophication potential (Muñoz et al., 2010). Thus, factoring in this stage of a life cycle of food is essential for studies that strive for comprehensive and multidimensional impact assessment. However, only one research team (Muñoz et al., 2010) has fully investigated this stage within the study of the environmental impacts of dietary patterns.

3.2.3.3 Environmental impact categories

As mentioned previously, potential environmental impacts associated with the production and consumption of food can manifest in a diverse range of impacts such as climate change, biodiversity loss, acidification, and resource depletion. Among the variety of impact categories, carbon footprinting seems to prevail in the current LCA research (Berners-Lee et al., 2012; Carlsson-Kanyama & González, 2009; Hendrie et al., 2014; Kramer et al., 1999; Macdiarmid et al., 2012; Pathak et al., 2010; Risku-Norja et al., 2009; Vieux et al., 2012; Weber & Matthews, 2008).

Carbon footprinting is also a fundamental part in the food miles research, where the GHG emissions are calculated from the transportation of food. One of the likely precursors of the narrow focus on GHG emissions is the policy orientation towards the global reduction of carbon emissions. In Canada, 30% of the agricultural products and consumed foods are imported and associated with 3.3 million metric tons of GHG in food miles related emissions (Kissinger, 2012). This study on carbon footprinting of the country's imports has also demonstrated that transportation of fruit and vegetables is linked to the highest GHG emissions (Kissinger, 2012).

Other common impact categories used in the analysis of the food consumption include land use (van Dooren et al., 2014) and cumulative energy use (Druckman & Jackson, 2009; Jungbluth et al., 2000); and a limited number of studies include a full range of impact categories such as ecosystem and human toxicity, acidification, eutrophication, ozone layer depletion, carcinogens and other (Baroni et al., 2007; Davis et al., 2010; Meier & Christen, 2012a; Muñoz et al., 2010).

The importance of including other impact categories is supported by the findings of recent studies. Thus, land use may account for around 5-13% of the total environmental impact, water use – up to 45%, fossil fuel use - around 18% (Baroni et al., 2007). However, water use seems to be neglected despite its profound environmental effect. Given that agriculture, as a part of the food chain, accounts for 70-80% of the human freshwater use (Goodland, 1997), it is crucial to include it in impact assessments.

Van Dooren and coworkers (2014) state that the essential environmental impacts of food consumption encompass climate change, fossil fuel and mineral resource extraction, biodiversity loss, ecosystem change, ozone layer depletion, acidification and eutrophication. Thus, to ensure completeness of assessments of the environmental impacts associated with the food system, all the above-mentioned impact categories should be included in the analysis. However, in practice, it is often difficult to obtain reliable data to analyze all impacts of food system.

3.3 Nutritional quality assessment

3.3.1 Health implications of diets

A number of epidemiological studies have indicated a strong correlation between dietary patterns and health implications in humans and animals.

Animal-based diets are found to be linked to medical conditions such as type II diabetes, cardiovascular diseases, stroke, cancer, Parkinson's disease, hypertension, obesity, and some foodborne illnesses, to name a few (Barnard, Nicholson, & Howard, 1995; Goodland, 1997; Sabaté, 2003). High saturated fat and high sodium intake can potentially increase the risk of cardiovascular diseases (Wilson et al., 2013). Saturated fat content is high in the five most common foods in animal-based diets: meat, cheese, milk, butter and eggs (Hu et al., 1999).

Dietary animal protein has been linked to cancer based on extensive research by Campbell and Campbell (2005), Youngman and Campbell (1992) and Schulsinger Root and Campbell (1989). Ovarian cancer was linked to dairy consumption (Larsson, Bergkvist, & Wolk, 2004),

breast cancer was found to be associated with animal protein intake (Sieri et al., 2002), colorectal cancer is strongly correlated with meat consumption (Chao et al., 2005), while colon and prostate cancer is reduced by half when excluding meat from the diet (Fraser, 1999). Protein-rich animal foods are linked to higher incidences hypertension and heart disease (Barnard et al., 1995), gallbladder disease (Barnard et al., 1995) and kidney stones (Breslau, Brinkley, Hill, & Pak, 1988), obesity and diabetes (Barnard et al., 1995), increased aging bone loss and hip fractures (Lanham-New, Lee, Torgerson, & Millward, 2007), Crohn's disease (Shoda, Matsueda, Yamato, & Umeda, 1996) and other NCDs.

In contrast, plant-based diets have been associated with lower diseases and mortality rates (Dunn-Emke et al., 2005; McCarty, 1999, 2001; Turner-McGrievy et al., 2008). Plant-based protein sources, as alternatives to animal-based proteins, are found to reduce the risk of cancer, obesity, and cardiovascular diseases (McCarty, 1999). However, plant-based diets can also potentially increase the risk of some nutrient deficiencies. Although they are richer in dietary fiber, folic acid, vitamins C and E, iron, and magnesium than animal-based diets, they also might lead to a lower vitamin D, calcium, zinc, and vitamin B-12 intake (Craig, 2009). These deficiencies, however, might be offset by proper supplementation.

High sodium intake is likely to increase the risk of cardiovascular diseases (Wilson et al., 2013). Processed foods are known to have high sodium levels, thus adverse health implications occur regardless of the type of diet, if the consumption of processed foods is high. Processed foods are also often associated with higher calorie content. Research has shown a strong correlation between overconsumption of calories and obesity (Rolls, 2003). Thus, there should be a balance of nutritious foods in a healthy and sustainable diet.

3.3.2 Nutritionally-balanced diets

There are a myriad of diets ranging from diets based on religious and ethnic grounds to diets tailored specifically for medical conditions, including weight control. The list is long but it encompasses some of the most common diets such as Western diet, Mediterranean, pescetarian, lacto-ovo-vegetarian, paleo and a vegan diet, to name a few. Given the primary role of a diet as a nutrition source, looking at the diet from a health perspective is vital. To satisfy the requirements of a healthy and sustainable diet, investigating a diet from a purely environmental perspective is limiting. Diets should not only be environmentally friendly, but also nutritious, thus insuring nutritional security.

The most recent studies (Macdiarmid, 2013; Macdiarmid et al., 2012; Saxe et al., 2013; van Dooren et al., 2014) aim at balancing health and sustainability in diets and strive to understand how to achieve it. Such research suggests that it is feasible to formulate a diet which is both environmentally sustainable and nutritionally sound. However it also shows that current presumably 'healthy' diets are not always sustainable due to various sourcing of food or addition of potentially-high impact fruit and vegetables, to name a few (Buttriss, 2013; Vieux et al., 2013). However, a thoughtful composition of a diet can substantially reduce its environmental impact and increase nutrition value (Macdiarmid, 2013).

The current understanding of sustainability concept in a diet is poor. At the same time understanding what comprises a healthy diet is also vague. Recent studies show that there seem to be a number of misconceptions such as protein requirements for a healthy diet and sources of that protein. Focus on high protein consumption likely originates from media promoting weight loss programs and low carbohydrate low fat diets (Macdiarmid, 2013). Such misconceptions and misinformation of the general public could potentially hinder the formulation and further transition towards an H&S diet (Macdiarmid, 2013).

Plant-based diets have been found to be safer by some researchers and are nutritionally superior to animal-based or mixed diets (Eshel & Martin, 2006). However, knowing the amount of animal-based food and frequency of its consumption is crucial and sometimes is a decisive factor in nutritional assessment of such diets. Thus, an animal-based Mediterranean diet is considered as a foundation for the Food Pyramid, a nutritionally balanced dietary guideline (Ciati et al., 2012).

According to Konrad Bloch, the Nobel biochemist laureate (Goodland, 1997), humans do not necessarily need to consume animal flesh to stay healthy, although a relatively small portion of meat in a diet might be environmentally benign (van Dooren et al., 2014). Thus, a plant-based diet such as a vegan diet is seen as nutritious and healthy. A vegan diet seems less attainable for the general public due to a massive gap between the average diet and a vegan diet (van Dooren et al., 2014). Although, a common barrier to recommending a vegan diet to the general public is the supply of some nutrients, such as vitamin B12, iron, vitamin D, calcium, EPA and DHA fatty acids, some of these nutrients might be lacking in animal-based diets as well (Craig, 2009; van Dooren et al., 2014). A proper composition and supplementation of both diets can insure a balanced nutrient supply.

Supplementation seems to be overlooked by existing studies of environmental implications of diets. Studies considering local food production also often aim at investigating self-sufficiency of local food systems, with only a few of them factoring in nutritional security (Desjardins et al., 2010). However they fail to consider a variety of dietary patterns and special nutrient requirements for particular diets.

Apart from the concerns about vegetable and fruit intake, consumption of animal products, sufficient supply of nutrients in a balanced diet, in this day and age there is also a risk of overconsumption (Macdiarmid, 2013). This factor alone can profusely affect the health and environmental repercussions of diets. Thus, appropriate dietary guidelines and indicators should be applied to nutrition assessment of diets and formulation of an H&S diet.

3.3.3 Nutrition indicators

In the academic literature there seems to be a lack of common ground and standardization of nutritional quality assessment linked to sustainability of diets (Heller et al., 2013). Although there are universal frameworks to assess the environmental impacts, the diversity of nutritional assessment tools might seem confusing for an environmentalist to consider. It is also challenging to link the nutrition indicators with the health indicators and identify the relationship (Heller et al., 2013). However there are a number of nutrition indices that facilitate this linkage.

One of the most common references in the sustainability assessment of diets is the dietary guidelines. The paradigm which drives most of the dietary guidelines around the world is the conventional Food Pyramid. The first Food Pyramid, which presumably represents a nutritionally-balanced diet and stems from the Mediterranean type of diet, was proposed by the U.S. Department of Agriculture more than two decades ago (Ciati et al., 2012). It prioritizes food groups according to their impact on health in form of a pyramid. It has evolved over the years and has its variations in different countries.

The current Food Pyramid was successfully linked to the environmental performance of their components and presented in the form of the Double Food Pyramid in 2012 (Ciati et al., 2012). The Double Pyramid represents both the Food Pyramid and the environmental Food Pyramid. It indicates that the highly recommended foods such as fruit, vegetables, pasta, rice, potatoes, bread and legumes display the lowest environmental impact. The top of the Food Pyramid which encompass dairy, meat, fish, eggs and biscuits demonstrate the highest environmental impact (Ciati et al., 2012)

Although such a large-scale comprehensive approach to measuring the environmental performance of the entire food groups provides a big picture of the environmental impact of food consumption, the generalizability of the impacts of the food groups might mislead the public, skew the dietary guidelines and misinterpret the hotspots among the food items. Thus, grains, proposed as a low-impact food category also include rice, which has been found to contribute to GHG emissions on par with meat and dairy products due to methane emissions during the cultivation on paddy fields (Carlsson-Kanyama & González, 2009; Pathak et al., 2010). The Food Pyramid also ignores vegetarian, vegan, paleo and other diets which exclude certain food categories and thus have contrasting environmental performance. For this reason a diet-specific environmental assessment in concert with a less general nutrition indicator communicates a more accurate and realistic environmental performance.

Nutrient profiling is the classification of food items according to their nutrient content and contribution to a balanced diet. This profiling provides a score for a meal or a diet (Heller et al., 2013). Some of these indexes are Nutrient Rich Food Index (NRF), Overall Nutritional Quality Index (ONQI) and Weighted Nutrient Density Score (WNDS) that assess the nutritional quality by evaluating the balance of beneficial nutrients and nutrients that are needed in moderation (Heller et al., 2013). Given that each index employs a different set of nutrients as a baseline for scoring, it seems challenging to compare the dietary recommendations and apply them as a standard in formulating a healthy diet. Moreover, the potential negative scoring of a food item or a diet might necessitate normalization for the purpose of being incorporated to the functional unit in the sustainability assessment of a diet (Heller et al., 2013).

A limited number of nutrition quality indicators are directly guided by disease risk factors. One such index is the Alternative Healthy Eating Index (AHEI-2010). Based on a scoring system as well, the index links chronic diseases and foods that possess preventive characteristics (Heller et al., 2013). Higher scores are associated with lower risk of particular chronic diseases. Another existing framework 'Global Burden of Disease' (GBD) showcases health risk factors based on lifestyle and dietary patterns (Murray et al., 2012). The leading dietary risks are shown to be diets that are low in fruit, vegetables, grains, nuts and seeds, and diets that are high in sodium, red or processed meat and sugary drinks (Lim et al., 2012). The GBD has a potential to set a benchmark in the sustainability assessment of diets, linking health and nutrition and being a comprehensive resource to complement the environmental assessment of diets. This framework may assist not only researchers in formulating the H&S diets in various geographical

regions and different groups of populations, but also facilitate the decision-making and formulation of above-mentioned dietary guidelines on a national level.

Understanding these dominant nutrition assessment instruments is crucial in incorporating the nutrition component in dietary assessment. However, in order to formulate a universal healthy and sustainable diet for a particular region or produce valid comparisons among different findings, it is essential to create a 'golden standard' or identify the best available assessment tool.

4. Thesis objectives and Rationale

The primary aim of this study is to understand the environmental impacts of dietary patterns in Ontario and establish links between nutritional and environmental components in sustainability assessment of food consumption. The specific objectives of this study are to:

- Determine the current dietary patterns in Ontario and formulate annual food baskets representing each of the dietary patterns;
- Quantify environmental impacts of current dietary patterns in Ontario, identify the primary hotspots and benchmark them against other countries;
- Assess nutritional quality of current dietary patterns;
- Identify improvement potentials for nutritionally balanced, environmentally friendly and socially acceptable dietary patterns.

This comprehensive and evidence-based approach will improve individuals' and society's understanding of the diet implications on health and environment and provide insights into improving the nutritional and environmental sustainability aspects of dietary patterns at a provincial scale. This knowledge may 1) serve as a guidance to consumers to make changes towards more sustainable practices that can potentially result in a cumulative positive impact on behavioral patterns, consumer choices and conscious and responsible consumption; 2) assist food supply chain stakeholders to identify the key areas for environmental improvements; 3) provide policy makers with a tool for setting healthy and sustainable dietary guidelines and monitoring the potential impacts resulting from activities within the food sector; and 4) facilitate environmentally friendly, nutritionally sound and culturally acceptable changes in the food consumption.

CHAPTER II. METHODOLOGY

This research project takes a life cycle approach to measure the environmental performance of dietary patterns in Ontario. The assessment of environmental impacts in the food sector occurs on multiple levels. Various researchers look at the food industry from a production or consumption perspective depending on the goals of their studies. They adopt an efficiency-oriented or demand-oriented approach and aim at improving the efficiency of production processes and logistics or changing consumer behavior (Heller et al., 2013). Given the key objectives and potential applications, a consumption-oriented approach is adopted in the present study.

The methodological approach used in this study is based on the quantitative and qualitative assessment of actual dietary patterns, quantitative and qualitative assessment of food availability statistics, as well as the life cycle assessment (LCA) and nutritional quality assessment that are quantitative by nature.

The study involved three key stages. First, dietary intakes were examined based on the Canadian national health survey, allowing an assessment of dietary choices and foods commonly consumed by Ontario population and formulation of food baskets representing dietary choices. Second, an LCA tool was used to estimate potential environmental impacts associated with the production and consumption of the food items in each of the food baskets. Third, the food baskets were compared to dietary intakes recommended by Canada's Food Guide, and environmentally beneficial adjustments were suggested to optimize their nutritional value.

1. Life Cycle Assessment Methodology

LCA of food baskets representing dietary patterns in Ontario was conducted according to the ISO14040 (2006) and ISO14044 (2006) standards. The analysis included goal and scope definition, inventory analysis, impact assessment, and interpretation and presentation of results. The modeling was performed and comparison was analyzed with TRACI 2.1 impact assessment method in SimaPro v 8.0.2 software.

1.1 Goal & Scope

The goal and scope definition sets the terms for the life cycle modeling of impacts associated with a product or a process. This step in the environmental LCA involves methodological decisions, outlines assumptions and guides further data collection. The goal definition and scoping determines the functional unit for the LCA, describes the environmental impacts that are assessed in the study and defines the boundaries of analysis.

1.1.2 Functional Unit

LCA of any product is conducted on the basis of a functional unit, which provides a reference for measuring the inputs and outputs of the system (Heller et al., 2013). In comparative studies the functional unit also serves as a basis for comparison between various products or systems that perform identical functions.

The function of a diet is to supply nutrition and energy to the body. In this study, the food baskets represent the dietary patterns observed in Ontario and serve as reference units in the LCA.

Each food basket represents the total annual food consumption of a person exhibiting a particular dietary pattern. This amount was extrapolated based on the average intakes reported on single days by 10,723 Ontario residents. Thus, as functional units, they reflected a combination of the time-related and nutrition-based food intake, which provided an adequate basis for further comparison.

The energy content of the food baskets was intentionally balanced and incorporated for the different food baskets to be comparable according to the same functional unit. The annual calorie intake was based on the recommended daily calorie intake for the average person in the sample Ontario population (51% of women of the average age of 38 and 49% of men aged 36). To determine the daily calorie requirement, the activity level was assumed to be low, which typically includes general walking, household chores as well as some moderate physical activity during leisure time (Health Canada, n.d.-c). Thus, the daily age and gender-weighted calorific equivalent of each food basket was determined as 2,294 kcal. The value was extrapolated to the annual calorific intake of 837,436 kcal (Health Canada, n.d.-c). Each formulated food basket included the most commonly consumed foods and beverages that are characteristic to the

corresponding dietary pattern. An LCA of each food basket was performed to compare the environmental impacts of current dietary patterns in Ontario.

1.1.3 Impact categories

Given the political context in Canada and Ontario particularly, GHG emissions were the key impact to quantify in the present analysis. Due to limited data availability, it was feasible to collect the environmental data across all food groups only for this impact category. The GHG emissions were standardized to CO_2-equivalents and measured using the TRACI 2.1 impacts assessment method as the Global Warming Potential (GWP) over a hundred year time period.

1.1.4 System boundaries

The scope and boundaries that are set out by researchers can significantly predetermine outcomes, so choosing the stages of production or consumption is crucial in achieving meaningful results. Looking at the food sector from a life cycle perspective seems to be an overarching approach by which researchers are likely to gain a better perspective and understanding of all the impacts that both production and consumption of food entail. Given the consumption-oriented approach of the current study and existing data constraints, a farm-to-fork system boundary was set in the present study.

The life cycle of ingredients in each of the food baskets encompassed all pre-farm production of fertilizers and pesticides, farm-based operations, transportation to processing facilities and retail, processing (where applicable), production of packaging, transportation of food baskets home, home storage, food preparation and dishwashing. Production of capital goods (farm machinery, buildings, cooking equipment and other), storage at retail, port and distribution centers and waste management were not covered in the present study due to data gaps or negligible impact on a life cycle basis. Detailed information for each food basket ingredient can be found in the Supplement 1 Appendix B.

The geographic boundaries of the study were limited to Ontario, Canada, where the food consumption occurred. The production of the various food products considered is scattered around the world and were assessed according to statistics on average production and imports over the past five years (Industry Canada, 2014; Kissinger, 2012).

2. Life Cycle Inventory and Data collection

The life cycle inventory describes the resource use and waste flow attributed to a product or a process. This step involves collecting activity level data (material or energy use) and emission data (emissions associated with the use of the resources). For the present study, activity levels included the type and amount of food consumed on an annual basis by Ontario residents within corresponding dietary patterns, distance traveled for grocery shopping, packaging used for transporting and storing food items, electricity consumed for processing and cooking, among others. Emissions were based on literature values and LCA databases within SimaPro and included waste flows to air, water and soil.

The data collection was carried out to identify the current dietary patterns in Ontario and form corresponding food baskets, as well as to estimate their environmental implications and nutritional quality.

2.1 Identifying dietary patterns in Ontario

Within the scope of this study, dietary patterns were identified based on the actual one-day food consumption of a sample Ontario population recorded in the Canadian Community Health Survey (2004).

Although existing published data provide details on food consumption in Canada and particularly Ontario, they do not provide a substantial basis for identifying consumption patterns. The data are often presented as frequencies of consumption for various food categories, individual food expenditures, food intake per capita or total amounts of food consumed (Statistics Canada, 2002a, 2002b, 2010). For example, a study on the food flow in the Region of Waterloo, Ontario (Harry Cummings & Associates Inc., 2005) developed a local food basket based on the Food Expenditure Survey and Health Canada's National Nutritious Food Basket; however it represents an aggregate amount of food consumed per person in the Region. These preexisting data are useful for analyzing the food consumption of the average Canadian or an average resident of Ontario, but do not elucidate food consumption patterns required for the present study.

2.1.1 Canadian Community Health Survey

For this study the dietary data utilized were drawn from the Canadian Community Health Survey, Cycle 2.2 'Nutrition' (hereafter referred to as 'CCHS 2.2') and represent the most recent comprehensive dietary data available for the Canadian population. The survey was conducted through a partnership between Statistics Canada, Health Canada and the Canadian Institute for Health Information (Health Canada, 2004b). CCHS 2004 (cycle 2.2) was focused on nutrition and collected detailed data on dietary intakes among a representative Canadian sample. Although the 2015 Canadian Community Health Survey will provide detailed dietary intake data for the first time since 2004, the data collection is still underway. However, the 2015 data will provide an opportunity to evaluate the dietary changes over the past decade and environmental implications associated with consumption patterns and dietary shifts (Statistics Canada, 2015).

CCHS 2.2 is a cross-sectional survey that sampled 35,000 Canadians and provided estimates for health indicators and food intake on a provincial level. The goal of the survey was: to collect data regarding dietary intake, socioeconomic and demographic characteristics; to analyze food consumption patterns and use of nutritional supplements; to assess overall food and nutritional security; and to inform policy-makers at the provincial and federal levels (Health Canada, 2004b).

The population sample of CCHS 2.2 represented around 98% of the Canadian population and comprised individuals of all ages that resided in private dwellings across ten provinces. Statistics Canada ensured that each age group that corresponds to established Dietary Reference Intake (DRI) indicators was equally represented. The sample size for each province was defined as a square root of the provincial population. Three provinces Ontario, Manitoba and Prince Edward Island subsidized a larger sample for a better representation (Health Canada, 2004b).

For the purpose of this study, the sample of CCHS respondents was reduced to the sample Ontario population by selecting only respondents in Ontario and excluding breastfed babies and children primarily consuming babyfoods in their diet. The excluded population groups were considered to have a negligible effect on forming dietary patterns. The total number of respondents (10,723) in the final sample represented 96.8% of Ontario residents (11,997,928) (see Table 2 Appendix A for sample statistics).

The collected data included all the food items that were consumed on the recall day, including main meals, beverages and snacks. The respondents also had to specify the consumed

amounts in grams, preparation method, use of condiments, type of meal and time as well as place of food preparation and consumption (Health Canada, 2004b; National Cancer Institute, n.d.). The Automated Multiple-Pass Method was used to elicit a complete account of everything consumed on the recall day.

The CCHS 2.2 was used as a database for identifying the actual dietary patterns in Ontario. The Ontario population was segregated into clusters, based on the food intake patterns. The clustering analysis was performed by the Statistical Analysis System (SAS 9.4) at the South-Western Ontario Research Data Centre.

2.1.2 Clustering procedure in SAS

Two methods of clustering were used to create groups of population with similar dietary choices based on reported intakes for a single day. Corresponding food baskets were then formed based on the resulting dietary patterns. Cluster analysis is a widely accepted practice in establishing dietary patterns (James, 2009; Tukker et al., 2011; Wirfält & Robert 1997). Through clustering, CCHS respondents with similar food choices and food intake were identified and grouped together into clusters. These clusters represented a particular dietary pattern. Prior to clustering the sample population, a range of food products reported in CCHS 2.2 was grouped into broader food categories as described below.

Statistics Canada initially assigned all consumed foods and beverages in the survey with unique Nutrition Survey System (NSS) codes, a total of 501,186 NSS codes. The survey also suggested alternative coding based on Bureau of Nutritional Sciences (BNS) system which included 80 BNS codes, and Canadian Nutrient File (CNF) database, made up of around 24 CNF codes (Table 1 Appendix A).

Despite the existence of formal coding systems, re-categorization of the food groups appears to be a common practice among nutritionists and LCA practitioners. The existing studies illustrate a great variety of food classifications and indicate that food groups are often adjusted to align with the research question and purpose of the studies (Meier & Christen, 2012a). In particular, Hendrie et al. (2014) assigned food products to broader food groups according to the Australian Dietary Guidelines and also distinguished between 'core' (red meat, poultry, fish, dairy, eggs, breads, cereals, fruit, vegetables, unsaturated oils and spreads) and 'non-core' products (snacks, soft drinks, tea, coffee, sugar, processed meats, saturated fats, oils, and alcohol). Kramer et al. (1999) differentiated processed grains and starches (bread, flour, pastry),

beverages and products containing sugar (confectionaries, honey, spreads, soft drinks) among other common food groups. Bernes-Lee et al. (2012) applied food categories that were used in the UK retail stores for accounting and operational purposes.

In the present study, new food groups (nuCNF) were developed based on the CNF food coding system (Table 1 Appendix A). The 24 CNF food groups were adjusted to account for the type of meat and content of eggs and dairy in foods and beverages, and facilitate subsequent LCA. As a result, the food group 'Fats and oils' (CNF-4) was segregated into animal fats and plant-based oils. The 'Soups and sauces' food group (CNF-6) was distinguished between soups and sauces containing pork, beef, mixed meat, egg, fish and seafood, and dairy products. Each subgroup was assigned to a corresponding food group ('Beef', "Pork', "Fish', 'Dairy and egg' and 'Mixed meat'). The food group 'Sausages and luncheon meat' (CNF-7) was segregated based on types of meat (pork, beef, poultry, game meat and mixed meat). Cereals containing dairy products, such as milk-based oatmeal, were assigned to a subgroup (nuCNF-8.1).

Given varying inputs in the production and packaging, and associated food wastages, fruit and vegetables were separated from the fruit- and vegetable-based juices (Trolle, Mogensen, Jørgensen, & Thorsen, 2014). Beverages (CNF-14) containing or largely based on dairy (such as chocolate milk, milkshakes and alike) were assigned to the food group 'Dairy and eggs' (CNF-1) to distinguish them from other beverages.

For the purpose of the current study, peas and beans were assigned to the protein foods group 'Meat and alternatives' as a part of "Legume' food group. Green peas, snap beans and lima beans are considered beans and legumes in their mature state and are similar with regard to the agricultural production, although Canada's nutritional guidelines assign peas, snap beans and lima beans to the food group 'Vegetables' due to its fiber, folate and potassium content (Health Canada, 2008). However, according to the USDA, 'legumes and beans' food group can be arbitrarily assigned to either 'Vegetable and Fruit Group' servings or 'Protein Foods Group' (USDA, n.d.).

Categories of baked products (including bread, crackers, cookies and other products), sweets (chocolate bars, candies, etc.) and snacks (chips, popcorn and similar foods) were distinguished between products containing gelatin, egg or dairy, and products containing no animal-derived ingredients. Whole grains were separated from pasta due to distinctions in processing of grains for pasta. Mixed dishes (CNF-22) and fast foods (CNF-21) were reassigned to other food groups based on the type of meat and the content of fish, egg and dairy, and were

not disaggregated by ingredients. Thus, 'lasagna with minced beef' was assigned to 'Beef' food group, comprising beef-containing products; 'lasagna with meat, unspecified' was assigned to a mixed meat category. This ensured that the dietary clusters with restrictions did not include restricted foods.

The ingredient lists for the commercial products were found on the producers' websites. When the ingredients could not be located or the producer was not specified, assumptions were made (e.g. bakery bread does not contain dairy or egg) and ingredients were derived from food recipes on culinary websites (www.allrecipes.com, www.food.com). Knowing the ingredients of various food products helped assign these products into respective food groups (e.g. differentiating between snacks containing animal-derived ingredients from vegan snacks).

Following re-categorization of food groups, survey respondents with similar patterns of consumption of the above-mentioned food groups were clustered together. The average intake of food groups in each population cluster represented a corresponding food basket.

Cluster analysis of the Ontario population was based on the algorithm applied for estimating similarities in protein consumption in Europe (SAS, 2014) and a classic algorithm for performing cluster analysis with SAS (McCarthy, 2007). A pre-clustering DISTANCE procedure was performed to process the raw data. The procedure calculated the distance and similarity between observations (responses about food intake) by computing Euclidean distances. The procedure generated a distance matrix that served as an input to the clustering procedure. All the data entries describing food intake were standardized to weight in grams.

Based on the results of the DISTANCE procedure, the CLUSTER procedure calculated the variance between the observations and suggested the number of population clusters in the sample. The program suggested that there were 10, 13 and 18 population groups with similar consumption patterns that could be clustered together. First, the group of 10 clusters was examined to identify what dietary patterns these clusters exhibited. Similar analysis was performed for the groups of 13 and 18 clusters. In order to decide which group of clusters was suitable for further analysis, the groups of 10, 13 and 18 clusters were compared based on consistency of dietary patterns.

Subsequent examination showed inconsistency between resulting clusters. The most populated clusters in the groups of 10, 13 and 18 clusters differed significantly in their food choices. Thus, the main population cluster from the group of 10 preferred cereal, the key population cluster from the group of 13 - beef, while the main population cluster in the group of

18 – beverages. Only four clusters across the three groups demonstrated consistent food consumption patterns; however all four clusters were least populated. The results of the cluster analysis were not considered robust. Consequently, an alternative technique for identifying clusters was applied.

The overview of the diet-related literature was conducted to determine the most common food patterns and dietary styles across various populations. Following the overview, the responses from the CCHS 2.2 were examined with regard to whether the sample Ontario population exhibited similar consumption patterns.

Omnivorous, vegan and lacto-ovo vegetarian diets were identified as prominent dietary patterns in a number of studies (Baroni et al., 2007; Goodland, 1997; Meier & Christen, 2012a; Risku-Norja et al., 2009; van Dooren et al., 2014). Omnivorous diet refers to a consumption behavior without any dietary restrictions. Vegan diet is a plant-based diet, excluding meat, dairy, fish and egg products and often substituting these food groups with greater amounts of fortified soy-based products, legumes, nuts and seeds (Meier & Christen, 2012a). Lacto-ovo vegetarian dietary style is described as plant-based diet including egg and dairy products, but excluding meat- or fish-based products (Meier & Christen, 2012a). The actual food items that substitute meat, fish and dairy in the vegan diet and meat and fish in the vegetarian diet were identified through the CCHS 2.2 responses.

Another dietary style identified in the literature was pescetarianism (Eshel & Martin, 2006). According to the environmental and bioethical food chain ranking by Goodland (1997), human diets change according to the hierarchy of the species within a food chain. The key differentiation in carnivorous diets is made between cold- and warm-blooded animals. The pescetarianism is a basic carnivorous diet, incorporating consumption of cold-blooded animals (fish, amphibians) but no other meat.

The next in the food chain are the warm-blooded animals, particularly birds. Certain variations of carnivorous diets incorporate only white meat along with optional consumption of fish. The exclusion of red meat might potentially stem from environmental, ethical and health motives. For the purpose of this study, the distinction of red and white meat was based on the Goodland's categorization of meat (Goodland, 1997). As a result, the 'No Red Meat' dietary pattern is primarily based on white meat, or poultry (Eshel & Martin, 2006; Goodland, 1997; Sanfilippo et al., 2012).

Carnivorous diets are also differentiated on the basis of the type of red meat such as beef, pork or mixed meat. Taking into consideration ethnic diversity of Ontario population, certain population groups may abstain from pork (e.g. Jewish, Muslim) or beef (e.g. Hindu) in their diets (Statistics Canada, 2001). These dietary patterns may be labeled as 'No Beef' and 'No Pork' variations of carnivorous diets.

The array of dietary styles included in the analysis encompassed vegan, vegetarian, pescetarian and omnivore diets along with carnivorous diets excluding red meat, pork and beef. The SAS software was further programmed to identify respondents that exhibited one of the above-mentioned dietary patterns based on their real-life one-day food-intake reports.

2.1.3 Formulating the food baskets

The cluster analysis identified the population groups with similar food choices exhibiting a particular dietary pattern. The groups were labeled 'Vegan', 'Vegetarian', 'Pescetarian', 'No Red Meat', 'No Pork', 'No Beef' and 'Omnivorous'. The SAS software produced a list of food groups consumed within each dietary cluster and the average amounts of each food group. The share of each food group in the final food basket was calculated based on the consumed amounts. For example, the average amount of the 'Fruit' food group consumed in the 'Vegetarian' dietary pattern was around 139 grams, or 8% of the daily food basket.

The SAS program also produced a detailed list of all the consumed food items for each food group within each dietary cluster. Due to confidentiality regulations for CCHS, only responses that were common among more than five respondents in each cluster were released by the Research Data Center (before applying survey weights that indicate the number of people with similar socio-economic characteristics that the respondent represents).

The list of the most commonly consumed items was created by selecting the food items consumed by more than 5% of respondents in each dietary cluster. For example, for fruit, respondents representing the 'Vegetarian' dietary pattern primarily consumed raisins, oranges, grapes, apples, bananas. Other fruits that were consumed by less than 5% population were not included. Preliminary daily food baskets were formed by including all commonly consumed foods in each of the dietary clusters. The percentage contribution of all the food items to the total consumed amount of the corresponding food group was calculated based on the proportions in which they were consumed.

The list of commonly consumed items within each food group was matched with the available life cycle inventories. Only food items for which the life cycle data were available were included in the final food baskets (Tables 1, Appendix B). For example, in the 'Vegetarian' food basket, only carrots, lettuce, tomatoes, whole canned tomatoes, canned tomato puree and onions were chosen due to unavailability of life cycle inventory for garlic. Their consumed amounts equaled 12%, 14%, 14%, 19%, 13% and 28% of the total consumed amount for the 'Vegetable' food group. This translated to 20 grams of carrots, 23 grams of lettuce, 23 grams of tomatoes, 30 grams of whole canned tomatoes, 20 grams of tomato puree and 46 grams of onion per day. Resulting daily food baskets were extrapolated to the annual food baskets by multiplying all the consumed amounts by 365 days.

Calorie-adjusted annual food baskets for the subsequent LCA were formed based on the actual annual food baskets by proportionally increasing or decreasing the weight of the basket to reach the desired level of calorie intake. This ensured that all food baskets were compared based on delivering the recommended amount of calories to an average Ontarian over the course of one year. Protein-adjusted food baskets that were used in the sensitivity analysis were formed according to the same principle.

For a scenario analysis, nutritionally balanced food, environmentally friendly and socially acceptable food baskets were formulated for each dietary pattern. They were based on the actual annual food baskets and adjusted according to Canada's Food Guide recommendations and environmental impacts identified in LCA results for different food items. Nutritional assessment of each food basket was used as a guide in formulating a nutritionally optimal food basket for each dietary pattern (Section 2.3). The consumption of high-impact food items identified in the LCA was reduced and substituted with the low-impact alternatives. To ensure social acceptability of the proposed changes, all commonly consumed food items were maintained. Where reduction of consumed amounts was applicable, the intake reduction did not exceed 50% of the original level.

2.2 Estimating potential environmental impacts associated with dietary patterns

For the purpose of the study, only the most frequently consumed foods and beverages in each of the food categories in the corresponding food baskets were used in the LCA (Table 1, Appendix B). The food group 'water' (tap and spring still water) was excluded from the analysis as it was assumed to have little to no effect on the results. The 'game meat' category was

Table 1. Sample Life Cycle Inventory: One liter of orange juice in a plastic bottle

Mandarin orange (citrus), at farm			
Materials/fuels			
Ammonium nitrate as N at regional storehouse/RER U	0.0017143	kg	
Single superphosphate as P2O5 at regional storehouse/RER U	0.00071429	kg	
Potassium sulphate as K2O at regional storehouse/RER U	0.0014286	kg	
Irrigating/US U	0.0625	m3	
Fertilising by broadcaster/CH U	0.00071429	ha	
Parathion at regional storehouse/RER U	0.0000021429	kg	
Glyphosate at regional storehouse/RER U	0.000072	kg	
Diuron at regional storehouse/RER U	0.00011429	kg	
Pesticide unspecified at regional storehouse/RER U	0.000017143	kg	Metalaxyl
Pesticide unspecified at regional storehouse/RER U	0.00012857	kg	Bromacil
Pesticide unspecified at regional storehouse/RER U	0.0000078571	kg	Malathion
Copper oxide at plant/RER U	0.00014286	kg	
Emissions to air			
Ammonia; low. pop.	0.00010286	kg	
Nitrogen oxides; low. pop.	0.000029143	kg	
Dinitrogen monoxide; low. pop.	0.000029143	kg	
Emissions to water			
Nitrate; groundwater	0.0006	kg	
Phosphorus; river	0.0000017376	kg	
Phosphate; groundwater	0.00000049645	kg	
Mandarin orange (citrus), at processing			
Mandarin orange (citrus), at farm	1	kg	
Mandarin orange (citrus), at farm	0.02	kg	2% wastage
Electricity/heat			
Diesel burned in diesel-electric generating set/GLO U	0.021125	kWh	cooling while transporting
Transport, lorry 20-28t, fleet average/CH U	4.39582	tkm	farm to distribution center in Ontario
Transport, lorry 20-28t, fleet average/CH U	0.0588	tkm	distribution center to juice processing facilities
Canadian electricity mix (Ontario)	0.04875	kWh	storage in Ontario before processing
Orange juice, processing			
Materials/fuels			
Mandarin orange (citrus), at farm	2.08	kg	
Tap water at user/RER U	5.1	kg	
Natural gas, high pressure, at consumer/RER U	0.68	MJ	
Soda powder, plant / US U	0.0089	kg	as detergent
Nitric acid, 50% in H2O, at plant / RER U	0.0003	kg	as detergent
Electricity/heat			
Canadian electricity mix (Ontario)	0.15	kWh	
Orange juice, bottle, packaged			
Materials/fuels			
Orange juice, processing	1.01	kg	conversion to liters
Plastic bottle (1 liter)	1	p	
Electricity/heat			
Canadian electricity mix (Ontario)	0.0294	kWh	packaging and filling
Orange juice, bottle, retail			
Orange juice, bottle, packaged	1	l	
Orange juice, bottle, packaged	0.02	l	2% wastage at retail
Transport, lorry 20-28t, fleet average/CH U	0.51	tkm	from processing and packaging facilities to retail
Orange juice, bottle, consumed			
Orange juice, bottle, retail	1	l	
Orange juice, bottle, retail	0.18	l	18% wastage at household level

excluded from the analysis of the meat-based food baskets due to lack of available data and low consumed amounts.

It was out of the scope of the present study to measure the inputs and outputs and calculate the associated impacts on a life cycle basis for each of the food items. The data for the study were collected from existing LCA studies and published life cycle inventories of foods or production systems, import and production statistics in Ontario, and country-specific data for production practices, packaging, and transportation. Overall, 74 profiles of food items were created and used in the analysis of the food baskets. Profiles were also created for various types of packaging, processes and electricity mix (Table 1).

2.2.1 Food production

Given the limited availability of food-related LCA studies in Canada, particularly in Ontario, LCA studies and inventories from other countries were adopted for the Ontarian context. The published data available for Canadian products included average Canadian egg production and broiler chicken from Eastern provinces (Vergé, Dyer, Desjardins, & Worth, 2009b), cheese, butter, milk, yogurt and other dairy products from Ontario (Vergé et al., 2007), canola and wheat from Western provinces and corn and soy from Ontario (Pelletier, Arsenault, & Tyedmers, 2008), Ontario greenhouse tomato (Dias et al., 2014), pork from Eastern Canada (Mackenzie et al., 2014; Vergé, Dyer, Desjardins, & Worth, 2009a), beef from Western Canada (Beauchemin, Janzen, Little, McAllister, & McGinn, 2010), average Canadian turkey production (Vergé et al., 2009b), salmon from British Columbia (Ayer & Tyedmers, 2009; Pelletier et al., 2009), and apples from Nova Scotia (Keyes, 2013). Thus, these studies were adopted without change and it was assumed that Ontario produces or imports above-mentioned foods from corresponding geographical locations.

To identify the origins of other items in the food baskets, detailed product-specific trade statistics for Ontario were accessed for the past five years through Industry Canada's 'Trade Data Online' tool (Industry Canada, 2014). Given multiple trade connections between Canada and the rest of the world, it was not feasible to account for various import origins. The analysis only included countries that were the largest suppliers of a particular product (Table 2).

Published LCA studies were adopted without change if the origins of analyzed food items were identical to Ontario's import statistics (e.g. pineapple from Costa Rica accounts for 94% of pineapple imports; around 83% of virgin olive oil comes from Italy (Industry Canada, 2014)).

Inventories for other foods and beverages were adapted from European and American studies to represent Ontario electricity supply mix and local agricultural practices (e.g. use of natural gas in greenhouse heating system) (Ontario Energy Board, 2013). The detailed life cycle inventory for each product used in the analysis is available in Supplement 1 Appendix B.

Current studies on the environmental footprint of diets demonstrate controversial performance of organic production methods. For example, some studies indicate a poor environmental performance with regard to the GWP of diets based on organic products (Risku-Norja et al., 2009) while others support organic production as environmentally friendly based on a weighted life cycle impact assessment expressed in points (Baroni et al., 2007; Jungbluth et al., 2000). Controversy in the organic production can be attributed to the choice of impact category or, diverse geographical locations of these studies, the unique climatic conditions, agricultural practices, yield, product type and other area-specific factors. According to Saxe and coworkers (Saxe et al., 2013), product types often have more influence on the study results than the type of farming.

Given that 98% of the Ontario agriculture is based on conventional production, for the purpose of this study all the products were assumed to be produced in conventional agriculture ("The Facts About Conventional and Organic Agriculture," n.d.).

2.2.2 Food distribution

Distances for transporting food products from farms and processing plants were modeled based on food origins and transportation routes. The distances for imported goods that were shipped by sea were calculated with an online tool ("Portworld Distance Calculator," n.d.) from the port of origin to the port of Toronto, one of Canada's major commercial ports ("Ports Toronto," n.d.).

The distances from the port to the distribution center were calculated using 'Google maps travel distance calculator'. Locations of processing plants (where applicable) and wholesalers were determined for each product separately. Distances from the distribution centers to retail stores were assumed to be 500km on average. The mode of transportation and volumes of each imported food category were determined from import statistics and published Canadian studies on food miles (Kissinger, 2012). It was assumed that a diesel-powered truck (using emission index for process 'Transport, lorry 20-28t, fleet average/CH U') was used for transportation by road. Transport did not account for the weight of packaging or a return trip.

Table 2. Origins of commonly consumed food items

Product	Origin	Product	Origin
Dairy & Eggs		potatoes	Ontario
butter	Ontario	onions	Ontario
cheese	Ontario	tomatoes	Ontario
milk	Ontario	tomatoe puree	Ontario
egg	Ontario	**Vegetable Juice**	
Herbs & Spices		tomato juice	Ontario
salt	Ontario	**Nuts & Seeds**	
Fats & Oils		almonds	California, US
olive oil	Sicily, Italy	walnuts	California, US
oil canola	Alberta	cashews	Brazil
margarine	Ontario	peanuts	Georgia, US
Poultry		almond butter	Ontario
chicken	Ontario	peanut butter	Ontario
Mixed meat		**Beef**	
pepperoni, pork / beef	Ontario	beef	Alberta
Cereal		**Beverages**	
breakfast cereal, Cheerios	Ontario	carbonated drinks	Ontario
oats	Ontario	beer	UK
Fruit		tea	India
apples	Ontario	coffee, instant	Colombia
strawberries	Ontario	coffee, roasted and ground	Colombia
pears	Ontario	**Fish**	
oranges	California, US	canned salmon	British Columbia
melons, cantaloupe	Ontario	canned tuna	Thailand
papayas	Costa Rica	**Legumes**	
pineapple	Costa Rica	green peas	Ontario
grapes	California, US	soybeans	Ontario
bananas	Colombia	tofu	Ontario
Fruit juice		soy sausage	Ontario
apple juice	Ontario	canned snap beans	Ontario
grape juice	Ontario	snap beans	Ontario
orange juice	Ontario	**Baked goods**	
Pork		bread, white	Ontario
pork	Ontario	**Sweets**	
Vegetables		sugar	Costa Rica
olives	Sicily, Italy	**Whole grains**	
lettuce, iceberg	Ontario	rice, white, long	Arkansas, US
cauliflower	Ontario	**Flour**	
peppers	Ontario	wheat flour	Saskechewan
cucumber	Ontario	**Pasta**	
carrots	Ontario	spaghetti	Ontario
zucchini	Ontario	**Snacks**	
broccoli	Ontario	granola bar	Ontario
cabbage	Ontario	potato chips	Ontario

Given the large-scale operations of distribution (i.e. warehouses, storage) and retail facilities, the impact of a single product in the annual food basket at the retail is assumed to be negligible. Thus, environmental impacts related to the operations of distribution and retail centers were not included in the analysis.

2.2.3 Grocery shopping

Information about shopping patterns in Ontario was limited and was not provided by CCHS (2004), therefore assumptions about transportation of food items to households were made.

According to the 'MasterIndex Report' by MasterCard (MasterCard, 2008), an average Canadian makes 37 grocery 'stock-up' trips and around 76 quick store trips per year. Major grocery shopping usually occurs once a week on an average 3.5 kilometer-round-trip. Canadians typically make smaller trips for picking up snacks or perishable staples such as milk, bread or fruit, and travel an average of 2 kilometers each time. For the purpose of the analysis, the Ontario population was assumed to have similar shopping patterns as the rest of Canada. Thus, the total annual distance travelled for general grocery stock-up and short trips was 129.5 kilometers and 152 kilometers, respectively.

Proximity to home is the main reason for Canadians to visit a particular store for a quick shopping trip (MasterCard, 2008). It was assumed that it was made by foot or as a stop on the regular travel route, thus the distance was not included in the analysis. Given the longer distance travelled and size of the shopping activity for a general stock-up, it was assumed that the trips were made by one individual in an average passenger car.

Provided that one of the factors for choosing a particular store for stock-up shopping is having a wide range of products within one store (MasterCard, 2008), all shopping was assumed to be done within one store. Given that the Ontario population is more likely to bring reusable bags for shopping (MasterCard, 2008), it was assumed that no disposable bags were used at the check-out.

2.2.4 Home storage

Since grocery shopping was assumed to be done once a week with smaller purchases made throughout the week, the cold storage was assumed to be operating throughout the year. Annual energy requirements were calculated as 636 kWh based on a conventional 22-ft3 refrigerator

that was bought after 2001 ("Saving Electricity," n.d.). Home storage was assumed to be identical between all the food baskets.

2.2.5 Cooking

Cooking was assumed to be done for each ingredient separately rather than whole meals. For example, boiled carrot and boiled cabbage were assumed to be prepared separately, although they might be consumed as one meal in a real-life scenario, while cooked pasta, tomato puree and pan-fried ground beef might be consumed as lasagna. The cooking time and temperatures were estimated according to popular recipes on culinary websites that are likely to be used among the Ontario population ("All Recipes Canada," n.d.; "Food," n.d.). Due to lack of data on the use of specific kitchen appliances in Ontario, an electric range top with an electric oven served as a reference cooking appliance.

The energy use during cooking was calculated based on the use of a small burner (1,200W) using an online tool ("Energy consumption calculator," n.d.). Heating time for boiling food items was calculated for water of room temperature using an online tool ("Water heating time calculator," n.d.).

Although there are a variety of dishes that are prepared from similar ingredients throughout the year (roasted and steamed vegetables, boiled or baked potato, roasted and grilled chicken), only the most commonly consumed dishes or preparation types recorded in the CCHS (2004) (e.g. beef roast for beef products) were modeled in the LCA.

Cooking is often associated with the weight change of a product. The weight gain can be linked to increase in water content in dishes such as rice or legumes, while water evaporation during baking or frying might reduce the weight of a final product (Bognár, 2002). To account for weight loss and gain in foods during preparation, cooking yield factors per edible part of the product were calculated for a range of products and preparation methods based on the estimates of the Federal Research Centre for Nutrition (Bognár, 2002) and USDA (Showell et al., 2012).

2.2.6 Solid waste

Wastage occurs along the food supply chain for various reasons such as overproduction, defects or spoilage, weather effects, transportation, poor storage, cuttings and trimmings or consumer behavior, to name a few (Gooch, Felfel, & Marenick, 2010). Food waste is comprised of around 60% of avoidable waste and 20% of unavoidable (peelings, tea or coffee residues, meat

or fish bones and alike), while around 20% are potentially avoidable (bread or pizza crust, potato peels, etc.) (WRAP, 2008). Consequently, a larger amount of food is produced and purchased than the reported food consumption. Accounting for food waste strengthens the analysis and provides more realistic and accurate estimates of the environmental impacts associated with food production and consumption.

Estimates for realistic food wastage could not be obtained through the CCHS (2004) given that the focus of the survey was on the food consumption without including the food waste within household. Thus, the estimates were used from existing literature.

According to a George Morris Centre report (Gooch et al., 2010), an estimated 9% of all food wastage in Canada occurs at farm level, 3% - during transportation, 8% - in food services, 18% - during processing and packaging, while over 50% occurs at a household level. Statistics Canada also estimated that in 2007 around 6 million tons of solid food and 2.8 billion liters of beverages were wasted at retail and household levels alone (Statistics Canada, 2012). Although these sources provide an approximate distribution of food waste between stages of a life cycle and estimates of the overall food waste in Canada, the values could not be adopted in the LCA. The analysis required estimates of the waste mass at each stage of the life cycle for each product in the food basket.

Waste at a farm level was not accounted for, given that most impacts for agricultural products are calculated per product that is leaving the farm gate. The values of food waste before the point of sale were calculated based on the disappearance data for Canada (Statistics Canada, 2002a, 2002b). It was assumed that food waste occurs equally across all provinces, thus the percentage of food wasted on a national level is proportional to the provincial level.

Given very limited data availability on food waste in Ontario at retail and household levels, values for avoidable food waste in various food categories were adopted from estimates for UK (published by Trolle et al. (2014) and WRAP (2008)) and estimates for the Region of Waterloo, Ontario (Urrutia Schroeder, 2014). Detailed distribution of waste among food categories and life cycle stages is illustrated in Table 2 Appendix B. Unavoidable waste at a household level was also calculated for fruits and vegetables based on USDA estimates (USDA, 2014).

Food loss and wastage was assumed to occur equally among the different dietary groups. No specific food waste treatment technology was chosen and no waste management scenario was included in LCA. Thus, the impact of wasted food was limited to the avoidable GHG emissions associated with the overproduction of food products.

2.3 Assessing the nutritional quality of food baskets

To develop a healthy and sustainable diet, investigating food consumption from a purely environmental perspective is limiting. Dietary styles should not only be environmentally friendly but also nutritious, which ensures nutritional security. Hence, after the environmental performance of the annual food baskets was assessed, the dietary patterns were evaluated with regard to their nutritional value.

The CCHS-based nutritional assessments of food consumption in Canada, particularly Ontario, are publicly available and serve as a source to inform general public and policy-makers (Garriguet, 2004; Health Canada, 2004a; PHRED, 2004). However, existing assessments primarily focus on the average national or provincial food intakes and overlook various dietary patterns. They also mainly consider the frequency of food consumption, food security, food safety and food-borne disease prevention (Public Health Agency of Canada, 2012). The purpose of the nutritional assessment in the present study was to evaluate various dietary patterns in Ontario and their dietary quality.

In the academic literature there seems to be a lack of common ground and standardization of nutritional quality assessment linked to sustainability of diets (Heller et al., 2013). Although there are universal frameworks to assess the environmental impacts, the diversity of nutritional assessment tools might seem confusing. It is also challenging to link nutrition indicators with health indicators (Heller et al., 2013). However, there are a number of nutrition indices that facilitate this linkage.

Testing sustainability of existing dietary guidelines is one of the most widespread methods in the sustainability assessment of a diet. Many countries and geographical areas have a set of guidelines and recommendations such as U.S. Dietary Guidelines (Heller et al., 2013), Australian Dietary Guidelines (Friel et al., 2013), Nordic Nutritional Recommendations (Saxe et al., 2013), D-A-CH in Germany, Austria and Switzerland or UGB (Meier & Christen, 2012a), Dutch Dietary Guidelines (van Dooren et al., 2014) or Canada's Food Guide (Health Canada, n.d.-b). These national and regional guidelines are based on recommended daily allowances (RDA) that evaluate and regulate the daily intake of essential nutrients. The qualitative guidelines also complement these quantitative recommendations (e.g. higher intake of whole grains, lower fat content in milk and others) (Health Canada, n.d.-b). Canada's Food Guide was used as a benchmark for optimal nutrition in the present study.

Although the Food Guide is not suitable for assessing the nutrient intake of the population through the diet due to its focus on servings of the key food groups rather than the recommended daily intake of nutrients (Health Canada, 2004b), it was an appropriate reference point for the nutritional assessment given the purpose of the study. Although the nutritional assessment results might not depict the true state of affairs regarding the nutrient intake within the current dietary patterns, it produces a relative estimate of how well the population meets the dietary recommendations.

Key dietary guidelines from Canada's Food Guide that were incorporated in the modeling and nutritional assessment of annual food baskets included:

- Annual consumption of 730 servings of milk (skim, 1%, or 2%) and alternatives;
- 2,555 servings of grain products per year;
- 2,920 servings of fruit and vegetables, including more whole foods than juices and at least one green and one orange vegetable daily;
- 912.5 servings of meat and alternatives, including 104 servings of fish and frequent consumption of beans, lentils and tofu;
- Limited intake of sugar, soft drinks, sports drinks, energy drinks, fruit drinks, punches, sweetened hot and cold beverages and alcohol due to their high calorie and low nutrient content;
- Consumption of oils and fats within the range of 10,220 to 12,775 grams per year;
- Canola, olive and soybean oil as preferable sources of oils and fats;
- Limited consumption of butter, hard margarine, lard and shortening.

Nutrition-focused sustainability assessments of diets are successfully implemented and are widely accepted. Researchers assess sufficiency of a particular macronutrient (protein (Davis et al., 2010; González et al., 2011)) or a set of nutrients (carbohydrate, fat and sodium content (Berners-Lee et al., 2012; Risku-Norja et al., 2009; Trolle et al., 2014; van Dooren et al., 2014)). To account for a wide range of nutrients and create a well-balanced diet, researchers apply various nutrient indices (Nutrient Rich Food Index (NRF), Overall Nutritional Quality Index (ONQI) and Weighted Nutrient Density Score (WNDS)) that incorporate a balance of beneficial nutrients and nutrients that are needed in moderation (Heller et al., 2013). A limited number of studies also use disease-oriented indices such as Alternative Healthy Eating Index (AHEI-2010) or 'Global Burden of Disease' (GBD) that showcase the health risk factors based on lifestyle and

dietary patterns (Heller, 2013; Murray et al., 2012). Given that each of them employs a different set of nutrients as a baseline for scoring, it seemed challenging to apply them as a universal standard in formulating a healthy diet.

Within the scope of the present study, recommended protein content along with the Canada's Food Guide was used as a measure of diet's nutritional quality. According to Health Canada (n.d.), adequate daily intake of protein appropriate for the Ontario sample population is 50.91 grams, which translates to annual value of 18,581 grams. Based on protein content and dietary preferences, corrections were made and alternatives were suggested to substitute food items exhibiting poor environmental performance.

The scenario analysis was used to quantify the carbon emissions associated with the potential changes. The changes included an increase or a reduction of calories and protein to achieve the optimal levels recommended by Canada's Food Guide, substitution of high-impact food items to more environmentally favorable alternatives; and adjustment in the amount of key food groups towards recommended intake of fruit and vegetables, milk and alternatives, grain products and meat and alternatives.

The food baskets were modified in the scenario analysis to optimize their nutritional value while maintaining the dietary patterns and improving environmental footprint. To ensure the social acceptability of the proposed changes, the key food groups and protein sources were neither eliminated nor reduced by more than 50%. The ratio of consumed products was altered to make the diets both nutritionally optimal and environmentally sound. Alternative food baskets were then evaluated again in the LCA software to measure the difference in the associated carbon footprint.

3. Limitations

3.1 Limitations of CCHS & cluster analysis

The population clusters and corresponding dietary patterns were solely based on the single day food intake data. According to the National Single Day Food Consumption Report (Public Health Agency of Canada, 2012), extrapolating the 24-hour dietary recall data to an annual consumption has limitations. The composition of the annual food baskets was based on the assumption that each person maintained their food consumption pattern throughout the year identically to the reported intake. This may not necessarily represent the actual consumption of foods, calories and protein throughout a year due to day-to-day variations. More accurate extrapolation would require data on the frequency of food consumption and likelihood of consumption over a long period of time.

Respondents were assigned to pre-determined dietary patterns solely based on their 24-hour recall data. Thus, there is a possibility that respondents with varying consumption patterns were assigned to a dietary cluster that did not represent their usual food consumption. This misallocation of some respondents could occur in cases in which the food intake on the recall day was substantially different from usual intake on other days, or if the food groups that are key in differentiating the dietary patterns (pork, beef, red meat, dairy and egg) were consumed by the respondent on a regular basis but not on the day of the recall. Some foods might also be irregularly consumed but happened to be consumed on the recall day. Thus, collecting data for one or a few days might not provide a good indication of usual intake for an individual compared to a longer period of time. Commonly consumed everyday foods identified based on the reported intake on a single day might have affected the nutritional assessment results but sufficed for the purpose of the subsequent LCA.

The survey responses, indicating whether the reported food consumption represented the usual food intake or not, were used to account for this limitation. Although, the question addressed the food intake in terms of quantity rather than dietary preferences, it was considered as a proxy and the best available source of information at the time of the analysis.

Grouping respondents into pre-defined dietary patterns could also potentially compromise accountability for seasonal variations in food consumption. If the average consumption was calculated for each food group based on the entire sample, the analysis would account for seasonal variability because the survey was spread out across the year. However, in this case, the

individual responses were first clustered based on their similarity and segregated from each other before calculating the average consumption. This could have resulted in responses from a particular season being clustered together. Thus, a 'Vegetarian' food basket could hypothetically contain only foods that were consumed in summer.

Food consumption patterns were identified based on the data collected in 2004. It is reasonable to believe that current consumption patterns may have changed since 2004. It is believed that, although food consumption behavior is difficult to change, the consumption patterns are not static (Gerbens-Leenes & Nonhebel, 2002). Moreover, new products regularly enter the market widening the choice and affecting the usual consumption patterns. The economic situation, financial instability, changes in production, import changes, social progress, immigration, rising education levels and aging can also potentially affect the food choices among the population (Grant et al., 2011; Thompson, n.d.). For example, meat prices drove the beef consumption down by 12% over the past decade (FCC, 2015). The financial crisis of 2008 could have forced some of the respondents to change their consumption habits due to changes in financial status. A growing number of dual-earner households leads to increased restaurant visits and consumption of convenience foods (Grant et al., 2011).

The cluster analysis also produced a list of most commonly consumed food items prepared in a variety of ways. The percentage contribution of all the items was calculated. Items and corresponding preparation methods that were common in more than 5% of population were recorded in detail, while others constituted the group 'Other (consumed by less than 5% of population)'. The actual consumption data describes a wide range of consumed food items and various methods of preparation. Choosing only commonly consumed items and most common preparation methods might have oversimplified the actual variety within a food basket.

The current vetting rules that are in place to protect confidentiality of respondents affected release of microdata from the CCHS 2.2 and limited the analysis of small population groups (less than 30 respondents before weighting, such as population representing the 'Vegan' dietary pattern) and rarely consumed foods that are consumed by less than 5 respondents (before weighting) in a particular cluster. This created a high level of uncertainty with regard to the choice of frequently consumed items and composition of the 'Vegan' diet, as well as results of subsequent LCA on these consumption patterns, since it was assumed that all the food items within each food group of the 'Vegan' food basket were consumed in equal proportions.

3.2 Limitations of LCA

The current study considers only the carbon footprint of the dietary patterns in Ontario. With a focus on a single dimension of the environmental impact, its complexity is underestimated. Given a sheer number of other significant impact categories across the entire life cycle, exclusively accounting for GHG emissions is limiting and is likely to skew the overall assessment results (Brodt et al., 2013). Thus, there is a common agreement that comprehensive research needs a wide spectrum of additional impact factors to understand the overall long-term implications of food consumption, and particularly, human diets (Heller et al., 2013).

Data quality and availability is another limiting factor in the LCA given that the quality of the results is strongly correlated to the quality of the raw data. Only a limited number of food items that were commonly consumed within each of the dietary pattern were included in the LCA due to existing data gaps. Due to unavailability of life cycle inventories, the following products were excluded from the analysis (most commonly consumed items in most of the food baskets are marked with asterisk):

- Condiments: vinegar*, soy sauce*, vanilla extract*, baking powder*, yeast, black pepper, mustard*, Worcestershire sauce;
- Fruit: plums, peaches, apricots, cherries, blueberries, watermelon, raisins;
- Juice: cranberry juice, mixed vegetable juice, lemon juice*;
- Vegetables: celery*, garlic;
- Nuts and seeds: hazelnuts, pecans, brazilnuts, flaxseeds;
- Legumes: lentils;
- Grains and cereals: barley*, various commercial breakfast cereals*;
- Fish: flatfish*;
- Beverages: commercial fruit punch;
- Snacks, sweets and baked goods: popcorn*, tortilla chips, crackers, chocolate bars, honey.

Missing inventory data on various processes and packaging materials can also compromise the accuracy of individual food product profiles. It was out of scope of the study to collect inventory data for each product. Given the limited data availability, the life cycle inventories were adopted from existing studies. Where applicable, study results on the GHG emissions associated with the production of a particular product (e.g. Canadian beef) were used for creating full product profiles. Data for processes, electricity and raw materials are largely based

on European databases (Ecoinvent), which may not represent the actual situation in Canada. Thus, more accurate and representative life cycle inventories have to be based on Canadian data rather than available inventories.

The results and their interpretation describe only potential impacts that may occur. There is a level of uncertainty related to the magnitude of the actual environmental impact. This creates a certain level of ambiguity and uncertainty and leaves room for interpretation.

3.3 Limitations of the nutritional assessment

Current nutritional assessment was primarily focused on the calorie and protein intake and recommendations of Canada's Food Guide. This limits the analysis of the nutritional quality of the food baskets with regard to supplying other essential macro and micronutrients. More complex modeling or nutrient score systems may be applied for more comprehensive nutritional assessment in future research.

It was outside the scope of the study to incorporate the use of dietary supplements in the diets. A broader analysis is likely to present a more accurate assessment of nutrient adequacy of the current dietary patterns.

The Food Guide was developed to assist Canadians in making choices to consume a balanced diet that promotes health and reduces the risk of nutrient deficiency and related diseases (Garriguet, 2004). Thus, it seemed as a valid reference point to model a balanced diet in the scenario analysis. Given the consumer focus of the present study, it was assumed that the Food Guide would be a likely source of the dietary information used by people planning their personal food intake.

Given that dietary guidelines often overlook various dietary styles such as vegetarian, vegan, and other similar diets which exclude certain food categories, a diet-specific recommendations and nutrient-focused assessment may need to be adopted. At the time of the analysis, no specific dietary recommendations for plant-based diets were available.

The food consumption and intake of recommended foods also varies on a day to day basis. Thus, it might not have been well captured in the collected data. Given that the food baskets adequacy was assessed based on the average consumed amounts and on an annual basis, it was assumed that these variations were accounted for by using the averages. It was also assumed that the recommended amount of servings would be cumulatively consumed throughout the year. Protein and energy requirements were also calculated based on the assumption that the

average person in the sample population has a low level of activity. The calorie and protein requirements change based on other activity levels, which may affect the overall nutritional quality assessment.

The food consumption within each dietary pattern was based on the average amount of consumed foods. However, the consumption may vary on an individual basis. Thus, the nutritional assessment may not accurately assess the nutritional adequacy on the individual basis. Distribution of the usual intakes could provide more useful information regarding the nutritional adequacy of individual diets and estimate the percentage of population with inadequate nutritional intake. However, for the purpose of this study, the average consumption within the population groups provided an insight into the nutrition value of a dietary pattern.

CHAPTER III: FINDINGS & INTERPRETATION

This chapter presents the study results obtained through the cluster analysis, nutritional assessment and environmental LCA of dietary patterns in Ontario.

The cluster analysis was used to identify current dietary patterns and formulate food baskets representative of the food choices in Ontario. The nutritional assessment allowed evaluating the extent to which current dietary patterns meet Canadian dietary guidelines and modeling nutritionally balanced versions of the food baskets. The LCA was applied to quantify the environmental impact of dietary patterns, measured as Global Warming Potential, and understand potential environmental changes associated with adopting nutritionally balanced, climate friendly and socially acceptable dietary patterns.

The LCA results include findings from the contribution analysis, sensitivity analysis and scenario analysis. Contribution analysis identified the primary sources of GHG emissions in the production and consumption of products within each of the food baskets. Sensitivity analysis tested key assumptions and robustness of the LCA results. Scenario analysis included modeling of nutritionally balanced versions of the food baskets according to Canada's Food Guide by altering the level of consumption of key food groups to the recommended levels. The consumption of food groups or individual food items that were identified as environmental hotspots was reduced and high-impact items were replaced with environmentally preferable alternatives.

1. Ontario Dietary Patterns

The cluster analysis showed that the Ontario sample exhibited all seven dietary patterns identified in diet-related literature (Figure 1). The dietary patterns were labeled 'Vegan', 'Vegetarian', 'Pescetarian', 'No Red Meat', 'No Beef', 'No Pork' and 'Omnivorous' dietary patterns. These dietary styles differed from each other based on the commonly consumed foods and inclusion of key food groups such as dairy, egg, meat and fish.

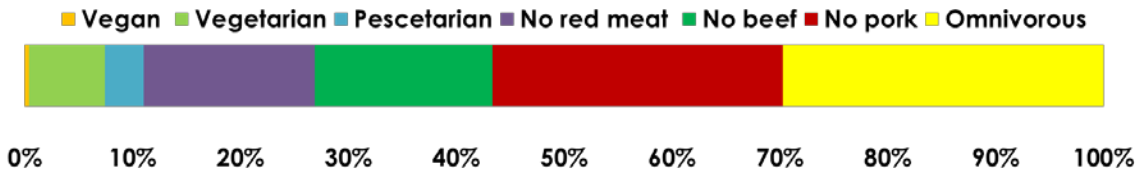


Figure 1. Breakdown of dietary preferences among the Ontario population

A third of the Ontario population followed an 'Omnivorous' dietary pattern on the day on which intake was reported (30%). Around 27% of surveyed Ontarians followed meat-based diet but avoided pork, 16.5% - avoided beef and 16% - avoided any type of red meat on the recalled day. The 'Pescetarian' dietary pattern was represented by 3.5%, whereas the 'Vegetarian' diet by 7% of the population. The 'Vegan' dietary pattern was the least represented with only 0.4% of population. The total vegan and vegetarian population in Ontario was larger than the Canadian levels, estimated at 4% by the American Dietetic Association and Dietitians of Canada ("Position of the American Dietetic Association and Dietitians of Canada: Vegetarian Diets," 2003).

The results obtained through the cluster analysis were used to formulate the food baskets representing each dietary pattern. The food baskets were labeled accordingly: 'Vegan', 'Vegetarian', 'Pescetarian', 'No Red Meat', 'No Beef', 'No Pork' and 'Omnivorous'. The consumption levels of the key food groups in each of the food baskets were expressed on a percentage and mass basis (Figure 2).

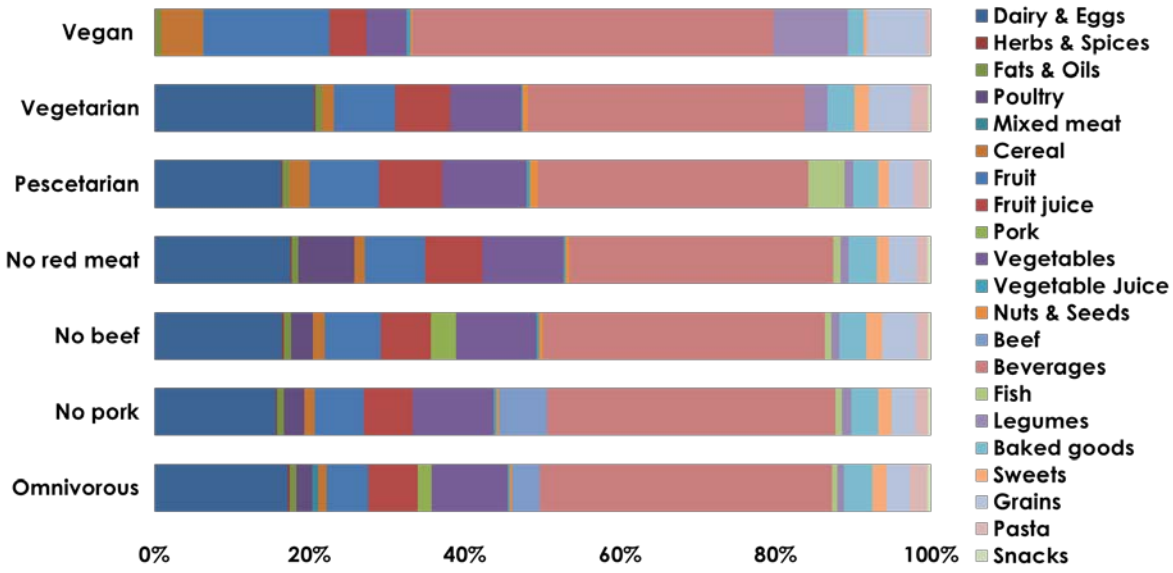


Figure 2. The composition of food baskets representing consumption of food groups by percentage. The food groups on the right are listed in order of appearance on the plot from left to right.

The food baskets significantly differed on a mass basis, ranging from 1.7 to over 2.3 kilograms of food per day. They were dominated by beverages, dairy and eggs, with the exception of the 'Vegan' food basket.

On a percentage basis, dairy and egg consumption was marginally larger in the 'Vegetarian' food basket than other food baskets (20%). Consumption of poultry was the highest in the 'No

Red Meat' food basket – two to three times higher than other meat-based food baskets. The 'Vegan' diet included a considerably higher share of cereal, grains, legumes and fruits; however it had a lower percentage of vegetables, nuts and seeds, baked goods, sweets, pasta and snacks compared to the other dietary patterns. The other food baskets had similar levels of consumption of these food groups. Consumption of pork in the 'No Beef' food basket was twice that of the 'Omnivorous' food basket. Consumption of beef in the 'No Pork' food basket was almost twice as high as in the 'Omnivorous' diet. Use of spices, fats and oils as well as consumption of beverages, fruit and vegetable juices was similar among the seven food baskets.

The food items that were commonly consumed within each food group and their corresponding preparation methods were identified for the seven dietary patterns (Table 1 Appendix B). The most common food items in the 'Dairy & egg' food group were eggs, milk, cheese and butter. The most consumed spice was salt. Margarine and canola oil were widely-used sources of fats and oils. The most common cereals were cooked oatmeal and commercial breakfast cereals such as cheerios, corn flakes and bran flakes. Apples, grapes, oranges and bananas were commonly found across all food baskets. Onions, tomatoes, lettuce and carrots were the most commonly consumed vegetables. Different variations of peanut butter were the main contributor to the nuts and seeds category, while other nuts and seeds varied from basket to basket. Coffee, tea and carbonated drinks such as cola and lime-soda were frequently consumed beverages. Among beans and legumes, green peas and canned or boiled snap beans were most popular. One of the most favorite snacks of Ontarians was potato chips. Jams, preserves and granulated sugar were most common in the 'Sweets' category. White flour and white rice were found to be typically consumed grain products. The widely used method of preparation for chicken and pork was roasting, whereas beef was primarily ground and pan-fried. Canned tuna and salmon were most common types of fish.

2. Nutritional assessment results

2.1 Recommended calorie and protein intake

The quantitative nutritional assessment of the current dietary patterns in Ontario according to Canada's Food Guide revealed that all the food baskets were considerably unbalanced (Figure 3; Table 3). Evaluation of the nutritional adequacy of the seven annual food baskets showed that most of the dietary patterns tended to consume an excessive amount of protein through their

diet and had a lower intake of recommended calories. However, taking into account the prevalence of the 'Omnivorous' and 'No Pork' diets, the majority of sample population exceeded both the recommended intake of protein and calories.

The consumption was considered representative of the usual consumption in the sample Ontario population. Around 93% of respondents assigned to the 'Vegan' dietary pattern described their 24-hour food consumption as 'usual'. The food intake was also identified as 'usual' by 73% of respondents in the 'Vegetarian' dietary pattern, 75% - 'Pescetarian', 86% - 'No Red Meat', 80% - 'No Beef', 74% - 'No Pork', 80% - 'Omnivorous' dietary pattern.

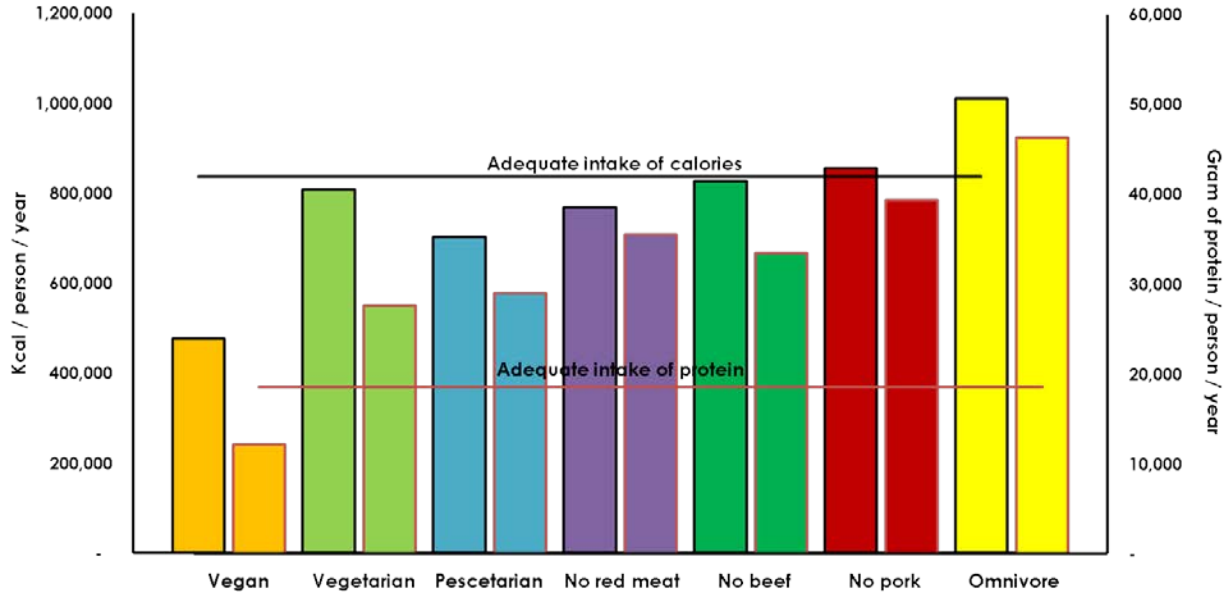


Figure 3. Calorie and protein intakes of Ontario population compared to recommended levels.

The optimal calorie intake for an average person in the sample, calculated according to Health Canada recommendations, was 2,294 kcal per day, or 837,434 kcal annually (Health Canada, n.d.-c). As shown in Figure 3, with exception of 'No Pork' and 'Omnivorous' dietary patterns (representing over 50% of Ontario population), most of the food baskets contained less calories than recommended. The 'Vegetarian', 'No Beef' and 'No Pork' food baskets had a relatively optimal calorie intake. The 'No Red Meat' food basket contained around 90%, while the 'Pescetarian' food basket – 84% of optimal calories. The 'Vegan' food basket had the lowest energy content at only half of the recommended level (57%). The 'Omnivorous' food basket, which represents 30% of the population, had the highest calorie intake level exceeding the

optimal level by 20%. Health Canada suggests similar trends of calorie imbalance by estimating that 50% of women and 70% of men have excessive calorie intake (Health Canada, 2012). The lower calorie content in other food baskets contradicts to the trends described by Health Canada (2012), which may be related to underreporting of energy intake or age- and gender-related differences between the dietary patterns or lower representativeness of other dietary patterns compared to the 'Omnivorous' and 'No Pork' diets.

Most of the dietary patterns were rich in protein (Figure 3). The optimal age and gender-weighted protein intake for the Ontario sample is 50.9 grams daily, or 18,581 grams annually (Health Canada, n.d.-a). The 'Vegan' food basket had the lowest content of protein (12,165 grams), which was 45% below the norm. The other food baskets exceeded the recommended amount of protein. The 'Vegetarian' food basket contained around 150% of optimal protein amount. Almost 60% of total consumed protein was primarily animal-based and sourced from dairy, egg and other meat alternatives. This directly corresponded to the food basket composition and a large share of dairy, eggs and meat in the overall food consumption.

The 'Pescetarian' food basket exceeded the recommended protein level by 56%. Over 75% of consumed protein came from dairy, egg, fish and other meat alternatives with 70 out of 75% being animal-based protein.

The 'No Red Meat' food basket had almost 200% of the recommended amount of protein. Dairy, eggs fish, poultry and meat alternatives contributed to over 78% of consumed protein; and the ratio of animal-based to plant-based protein was around 3 to 1.

The 'No Beef' food basket had 80% of protein above the recommended level. The primary source of the protein was dairy and eggs, fish, meat and alternatives (74%), with 71% of total consumed protein being sourced from animals.

The 'No Pork' food basket contained more than twice the amount of recommended protein intake. Dairy, eggs, meat, fish and protein-dense meat alternatives made up 80% of main protein sources. Animal-based foods accounted for 78% of consumed protein. This group consumed the largest fraction of beef.

'Omnivorous' food basket contained the highest amount of protein, around 250% of the recommended intake. The protein was primarily of animal origin (80%) from dairy products, eggs fish and meat.

Thus, the excessive protein intake in Ontario ranges between 150% and 250% of the recommended level, which is strikingly higher than that in the US (around 150% surplus) and

European countries such as Greece and Malta (around 190%) (de Marco A. & Velardi, 2014; Fulgoni, 2008). The prevailing share of protein is of animal origin (60 to 75% depending on the food basket), which is a similar trend with other countries such as Germany, Portugal, USA that consume 58-69% of protein from animal sources (de Boer et al., 2006; Smit, Nieto, Crespo, & Mitchell, 1999).

2.2 Recommended number of Food Guide servings for each Food Guide category

The nutritional analysis revealed that consumption of key food groups in Ontario's population was largely inadequate (Table 3). None of the dietary patterns satisfied the dietary guidelines with regard to the number of recommended servings of milk and its alternatives, grain products, fruit and vegetables, meat and alternatives including fish. Consumption of grains, fruits and vegetables were lower than recommended in all the food baskets, while meat and alternatives were largely overconsumed. This is in line with the recent findings in the Region of Waterloo, Ontario, where only three people in a thousand meet the dietary guidelines (CBC News, 2014; Minaker et al., 2013). The findings are also similar to national estimates, which is not surprising, given that over 40% of Canadian population lives in Ontario (Garriguet, 2004).

Table 3. Consumption of key food groups across the seven food baskets as a percentage of the recommended level. Lighter colors indicate lower intake, darker colors indicate exceeding levels of consumption.

%	Milk & alternatives	Grain products	Fruit & Vegetables	Meat & Alternatives	Fish
Vegan	0	66	61	65	0
Vegetarian	114	61	56	73	0
Pescetarian	72	46	77	117	427
No red meat	31	52	76	158	86
No beef	31	60	77	151	82
No pork	33	54	79	182	82
Omnivore	99	59	79	172	72

According to Canada's Food Guide (Health Canada, n.d.-b), an average person in the sample is advised to consume two servings of milk and its alternatives daily. On an annual basis, this translates to 730 servings. According to Garriguet (2004), milk consumption in Ontario is, on

average, below recommended levels, and a considerable percentage of population in each age group consumes less than the recommended level.

The same trend was observed in all the dietary patterns, except the 'Omnivorous' and 'Vegetarian' food baskets. The 'No Red Meat', 'No Beef' and 'No Pork' food baskets contained only a third of the recommended amounts of milk, while pescetarians consumed around two thirds of the optimal level. The 'Omnivorous' food basket had a target level of milk and alternatives, whereas vegetarians exceeded recommended amount by 14%. The excess of milk products in the 'Vegetarian' food basket can be explained by the potential tendency to replace meat products with dairy products, while other food baskets contain larger share of meat and fish. The 'Vegan' food basket, by definition, did not contain dairy products; data on the consumption of milk alternatives such as soy or nut milk was not available.

Consumption of grains across all seven dietary patterns was primarily based on processed grains in the form of flour, bread, white rice, pasta and breakfast cereals. Canada's Food Guide recommends an annual consumption of around 2,555 servings of grain products, including bread, cereal, pasta, couscous, bulgur, rice, quinoa and other similar products, with 50% of the consumed grain products being whole-grain (Health Canada, n.d.-b).

Consumption of grain products was similar across the seven food patterns (around 60% of the recommended level). The 'Vegan' food basket had marginally higher share of grain products, largely due to the higher consumption of rice and flour. The 'Pescetarian' food basket contained the lowest amount of grain products (46% of optimal intake). The lower grain consumption was also observed by Garriguet (2004) across Canada and particularly in Ontario.

Fruit and vegetable consumption among all food baskets was significantly lower than recommended intake levels, ranging from 56% in the 'Vegetarian' food basket to 79% of recommended value in the 'No Pork' and the 'Omnivorous' food baskets. This corresponds to the lower fruit and vegetable intake in Canada (Garriguet, 2004). Black and Billette (2013) have estimated that the Canadian population consumed fruit and vegetables largely in form of juices. However, this study showed that, on average, only around 20% of fruit and vegetable servings (30% on a mass basis) came from fruit and vegetable juices.

Animal-based diets demonstrated higher consumption levels of meat and its alternatives - from 151% in 'No Beef' food basket to 182% 'Omnivorous' food basket. According to Canada's Food Guide, an average Canadian should consume around 2.5 daily servings of meat or fish and alternatives such as nuts, legumes, tofu and other similar products (Health Canada, n.d.-b).

In the 'No Red Meat' food basket the recommended level was reached largely through the consumption of poultry (48%) and egg (30%). The 'No Beef' food basket primarily sourced meat and its alternatives from egg (32%), pork (24%) and poultry (21%). The consumption in the 'No Pork' food basket was largely based on beef (40%), egg (25%) and poultry (17%). The main contributors to meat and alternatives category in the 'Omnivorous' food basket were egg (26%), beef (25%), poultry (14%) and pork (12%). Across all the food baskets, alternatives such as nuts and legumes contributed to a lesser extent. This corresponds to the national estimates by Garriguet (2004) that suggest that meat consumption alone meets the recommended levels. However, the author did not provide estimates on the consumption of egg, fish, legumes, nuts and other meat alternatives that contribute to this food group.

The 'Vegan' and 'Vegetarian' food baskets did not contain meat and fish and had a lower amount of their alternatives compared to the recommended level. The 'Pescetarian' food basket contained high levels of meat alternatives (117%), mostly due to consumed amounts of egg and fish.

Two servings per week are recommended for optimal fish intake, which translates to 104 servings per year. The vegan and vegetarian dietary style naturally did not incorporate fish. Other food baskets contained lower levels of fish, ranging from 72 to 82% of optimal annual intake. The 'Pescetarian' diet which excluded any type of meat except fish, exceeded recommended intake level four times. Thus, around 3.5% of Ontario population consumed increased amounts of fish. According to the published estimates, only 15% of Canadians consuming fish meet the recommended amounts (Beaulieu, 2011).

Overall, the food patterns in Ontario were nutritionally unbalanced. The energy and protein content of the annual food baskets deviated from the recommended levels, similarly to the consumption of the key food groups such as milk and alternatives, grains, fruits, vegetables, meat, fish and alternatives.

3. Life cycle assessment results

The LCA results showed that on a farm-to-fork basis the animal-based dietary patterns ranged from 1,234 to 3,160 kg CO_2-eq., and thus had a higher environmental impact than the plant-based ones (Figure 4). The higher the consumed amount of meat products, particularly beef, was in an animal-based diet, the higher its carbon footprint.

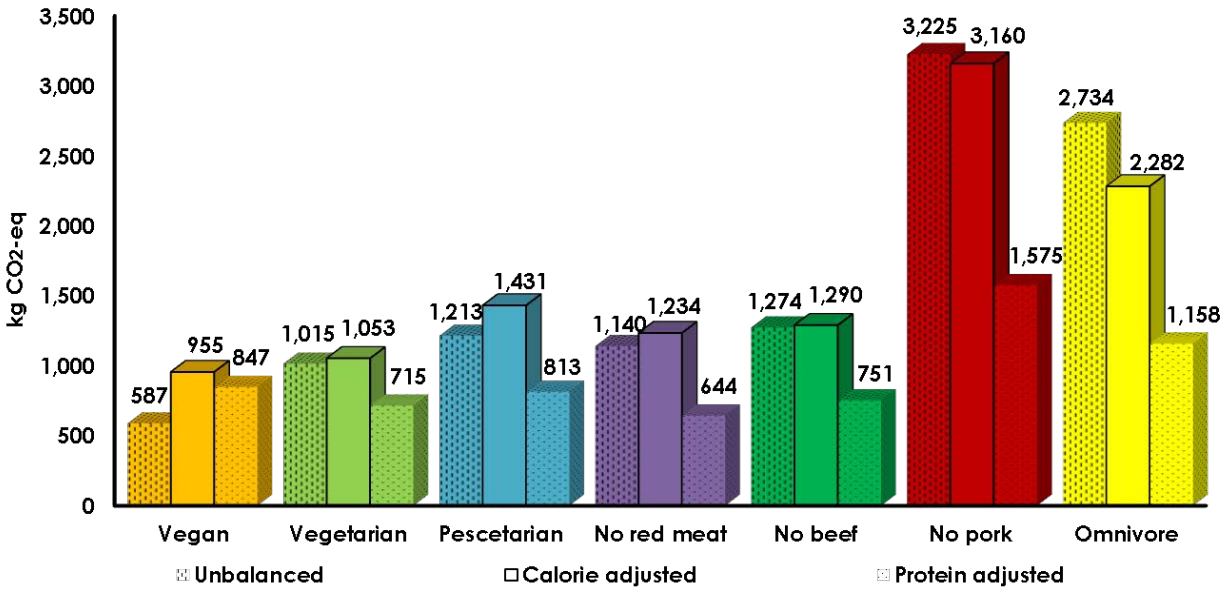


Figure 4. Environmental performance of Ontario food baskets measured by GHG emissions on a farm-to-fork basis. The impact varies depending on the choice of functional unit: nutritionally unbalanced realistic food baskets, calorie-adjusted or protein-adjusted food baskets

Based on the equalized calorie intake, the 'No Pork' dietary pattern had the highest carbon footprint (3,160 kg CO_2-eq.), while the 'Vegan' food basket had the lowest impact (955 kg CO_2-eq.), or a third of the GWP of 'No Pork' food basket (Figure 4).

The 'Omnivorous' food basket had the second largest impact, with GWP being 30% lower than that of the 'No Pork' food basket (2,282 kg CO_2-eq.). The 'Vegetarian' food basket had the second lowest carbon footprint which was only 3% higher than that of the 'Vegan' food basket (1,015 kg CO_2-eq.). The GHG emissions associated with the 'No Red Meat' and 'No Beef' food baskets were around 60% lower than the 'No Pork' food basket. The environmental impact of the 'Pescetarian' food basket was almost half of that of the 'No Pork' food basket (1,431 kg CO_2-eq.).

Existing studies almost unanimously confirmed that the diet containing relatively large amount of red meat is attributed to higher GHG emissions (Heller et al., 2013). On a farm to fork basis, average Finnish and Danish diets resulted in similar values - 2,810.5 kg CO_2-eq. (Virtanen et al., 2011) and 1,820 kg CO_2-eq. per person per year, respectively (Trolle et al., 2014). The GWP of an omnivorous dietary pattern in US resulted in 2,617 kg CO_2-eq. (Kim & Neff, 2009).

On a cradle-to-store basis, the results were also similar, despite the exclusion of the household-related processes. Thus, the GWP of an omnivorous diet in Germany was measured at 2,050 kg CO_2-eq. (Meier & Christen, 2012a). An average British diet produced 2,701 to 3,216 kg CO_2-eq. according to different estimates (Hoolohan et al., 2013; Berners-Lee et al., 2012). The GWP of the French omnivorous diet was associated with 1,522 kg CO_2-eq. (Vieux, 2012).

On a full life cycle basis, the 'Omnivorous' food basket was associated with a relatively lower annual GWP of 2,100 kg CO_2-eq. in Spain (Muñoz et al., 2010), and 1,285 kg CO_2-eq. in the Netherlands (van Dooren & Aiking, 2014).

The GWPs of the 'Vegan' and 'Vegetarian' diets in Ontario were considerably lower in comparison with other studies. The 'Vegan' diet was associated with 960 kg CO_2-eq. in Germany (Meier & Christen, 2012a) and 1,530 kg CO_2-eq. in USA (Kim & Neff, 2009). The 'Vegetarian' diet produced around 1,560 kg CO_2-eq. in Germany (Meier & Christen, 2012a), 1,850 kg CO_2-eq. in USA (Kim & Neff, 2009) and 1,876 kg CO_2-eq. in the UK (Berners-Lee et al., 2012).

The impact of these diets was relatively lower than that of meat-based diets in corresponding countries but on par with the meat-based diets in some other countries. Higher estimates for the 'Vegan' and 'Vegetarian' dietary patterns might be explained by varying diet composition, differences in the choice of commonly consumed foods, agricultural practices and geographical location. In case of the 'Vegan' dietary pattern, the difference may also be driven by the uncertainty associated with the commonly consumed foods within the Ontario vegan population.

Overall, the GWPs of meat-based diets in the literature are within the same range as the presented findings and are generally higher than GHG emissions associated with the vegan and vegetarian diets.

3.1 Contribution analysis: Largest impacts

Contribution analysis in LCA illustrates the overall environmental impact of a system and identifies the environmental 'hotspots', i.e. processes or resources that are responsible for the largest share of the overall impact. In this study, the hotspot analysis measures the contribution to climate change in terms of GWP.

As shown in Figure 5, the key contributors to the GWP in the Ontario food consumption were meat, dairy and egg. The impact directly corresponded to the share of these products in

each food basket. Thus, the 'Vegetarian' food basket containing the highest share of dairy and egg products (21%) demonstrated the highest GWP in this food category (53%). The 'No Pork' food basket had the largest impact in meat category (69%) due to its highest share of beef products (6%).

Generally, the protein-dense foods of animal origin such as beef, salmon, tuna, sausage, pork and cheese had a higher environmental impact than plant-based protein sources (legumes and nuts). These findings were expected due to similar trends in existing literature (e.g. Hendrie et al., 2014; Saxe et al., 2012). Studies on the protein efficiency in relation to the GHG emissions also support the findings that GWP of various protein sources differs significantly, largely in favor of vegetarian sources of protein (Davis et al., 2010; González et al., 2011).

Food groups such as fish, fruit, juices and beverages had varying impacts depending on the food basket. This was largely due to the different food basket composition and amounts of consumed product. For example, fish consumption in the 'Pescetarian' dietary pattern was four times higher than in other food baskets. Thus, corresponding GHG emissions from fish consumption were up to ten times higher in this food basket than others.

The composition of the 'Vegan' food basket was significantly different from the other food baskets due to uncertainty with regard to commonly consumed food items. Fruit category within the 'Vegan' food basket included a larger variety of tropical and local fruits and had a higher share of fruit compared to other food baskets. Thus, the GHG emissions associated with this food group were considerably higher.

The beverage group within the 'Vegan' food basket contained alcoholic beverages (beer) that were not commonly consumed in other food baskets. Beer made up around 10% of the overall impact of the 'Vegan' basket, which is similar to the findings by Saxe et al. (2012), where alcoholic beverages accounted for around 9% of the total impact. Thus, 'juice & beverages' category had a higher GWP potential compared to other baskets.

The food groups with the lowest GWP were pasta, snacks, cereal, sweets, fats and oils, seeds and nuts. This contrasts to other studies that demonstrated that 'non-core' foods such as sweets, snacks, fats and oils have the second largest contribution to the overall GWP (Hendrie et al, 2014). However, the present findings can be largely explained by a relatively lower share of these food groups in the food baskets. On average, fats and oils accounted for 0.8% of the food basket; pasta ranged from 0.6 to 2.2 % of the food basket, snacks - from 0.1 to 0.6%, cereal – from 1.1 to 5.4%, sweets – 0.5 to 1.9%, seeds and nuts – 0.3 to 1%.

Among the key household processes, grocery shopping and dishwashing had a lower impact than the food storage. Cold storage of food items such as dairy and eggs, meat, fish, fruit and vegetables, frozen beans and peas, juices and beverages contributed to up to 7% of overall GWP. The storage, proportionally, had a relatively higher impact in the 'Vegan' food basket (7 %) and the 'Vegetarian' food basket (6.5%) due to a relatively lower overall GWP of the baskets. Muñoz et al. (2010) also demonstrated a significant energy use during household processes such as storage and cooking (3.5% of the total energy use), but a relatively low contribution to the GWP. This could be explained by differences in the energy mix in Spain and associated emissions.

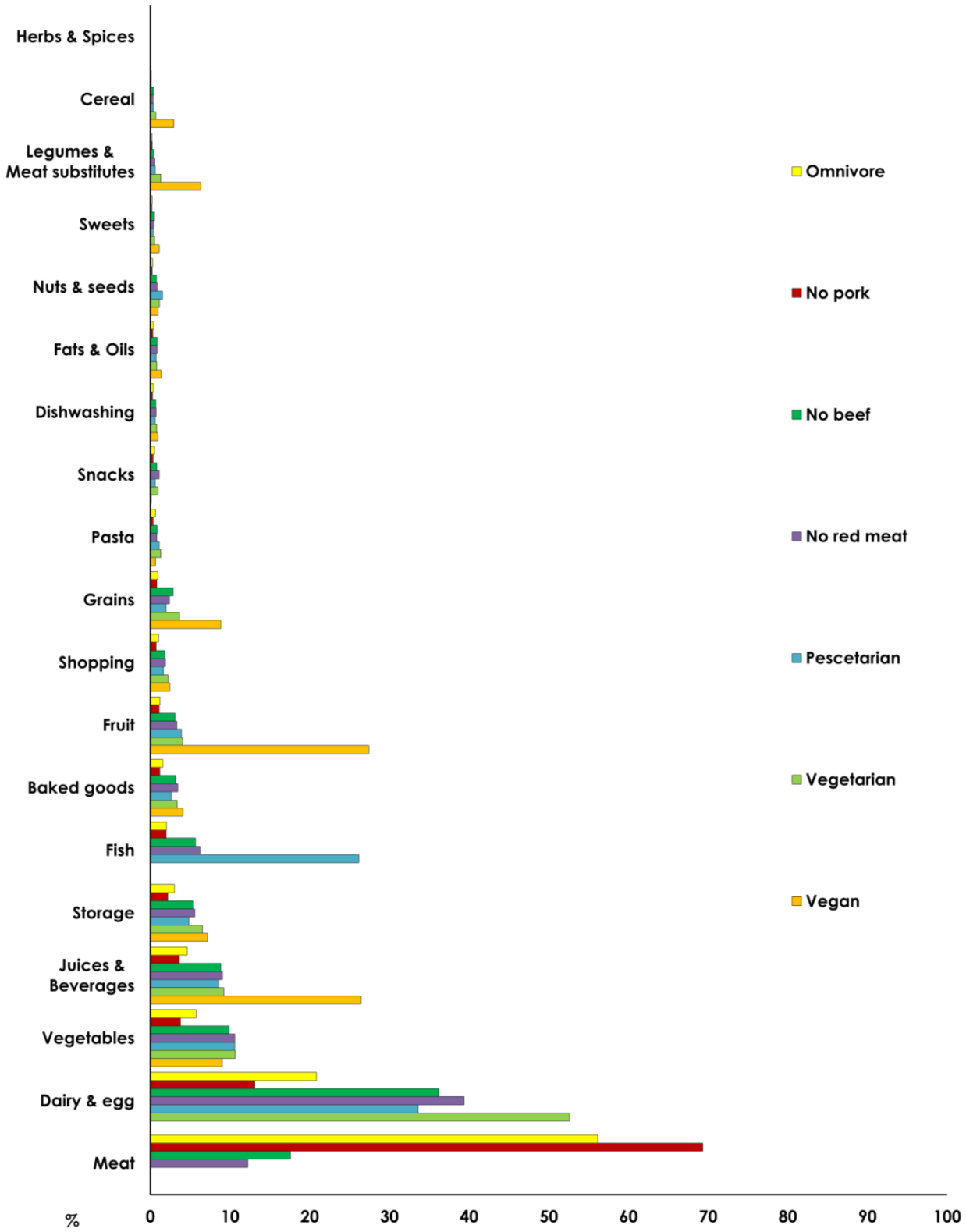


Figure 5. Contribution of key food groups and household processes to the overall GHG emissions associated with food baskets on a farm-to-fork basis.

3.1.1 'Vegan' food basket

Based on the calorie-adjusted functional unit, the 'Vegan' food basket exhibited the lowest carbon footprint among all seven Ontario food baskets (955kg CO_2-eq.). On a daily basis, it was associated with around 2.6 kg CO_2-eq. per person. The GWP of an actual unbalanced annual 'Vegan' food basket was 587kg CO_2-eq.

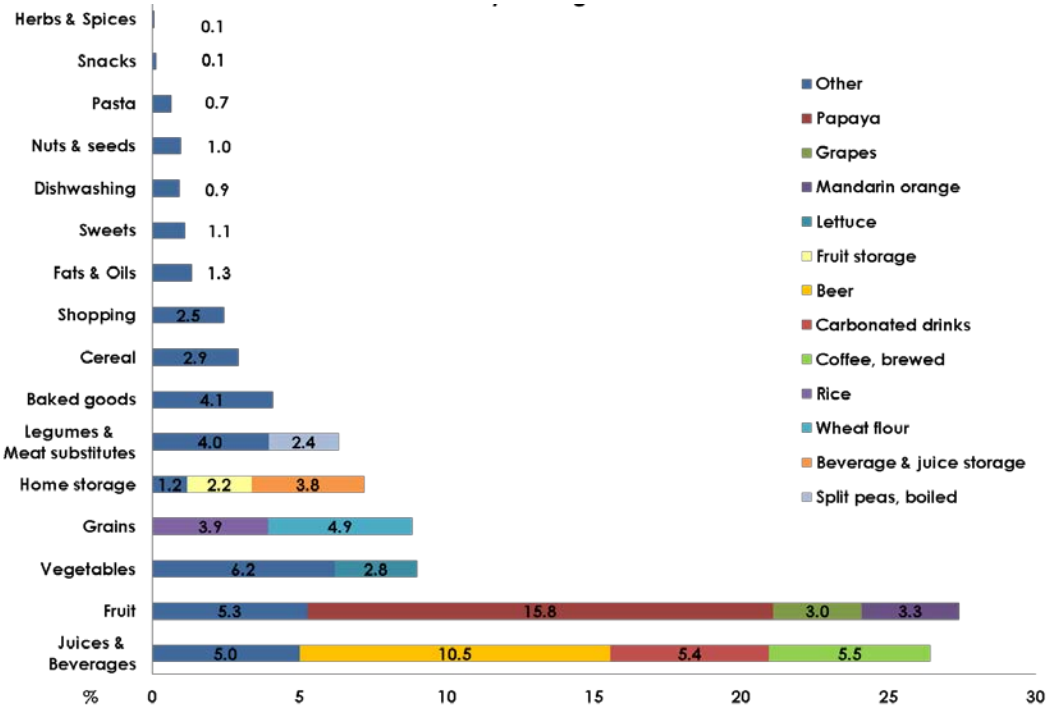


Figure 6. Key food groups and food items contributing to the environmental impact of the 'Vegan' food basket.

The food groups that contributed the most to the overall GWP of the 'Vegan' food basket were juices and beverages, fruits, vegetables, grains as well as legumes and meat substitutes (Figure 6).

Similar to the findings of Kissinger (Kissinger, 2012), the fruit import contributed substantially to the overall GWP. Papaya imported from Costa Rica was the main source of emissions within the fruit category and in the 'Vegan' food basket in general (15%), primarily due to the impact associated with the long-distance freight by air. Oranges and grapes imported from California, US respectively made up 3.3% and 3% of the overall GWP. The GHG emissions largely stemmed from the long-distance transportation by road.

Local greenhouse-grown lettuce contributed over a third of the impact from the vegetable food group. The impact was largely linked to the greenhouse operations, which made up around 80% of the impact. This is similar to the findings of existing studies that have shown that the produce grown in the greenhouses tends to have a higher GWP compared to the field-grown produce due to additional energy requirements (Carlsson-Kanyama, Ekström, & Shanahan, 2003; Jungbluth, Tietje, & Scholz, 2000).

The food waste along the supply chain and in the household also contributed to the overall impact of lettuce and other fruits and vegetables, due to the increased resource intensity and related emissions. Thus, for every kilogram of lettuce consumed, 1.62 kilograms were produced.

Beer imported from the UK had the largest impact in the 'juice and beverages' category (10.5%). Transportation accounted for the largest part of the impact due to the assumption that the beer was imported from the UK. Another hotspot was packaging. It was assumed that the beer was sold and purchased in the 0.33l aluminum can, so the total consumed volume of beer required substantial amount of packaging. Carbonated drinks accounted for over 5% of the overall GWP. Similar to the findings of Amienyo et al. (2013), packaging was the largest hotspot in the life cycle of the soft drinks. The consumed volumes also played a large role due to amounts of required packaging. Coffee contributed over 5% of the overall GWP with the farm operations having the largest impact.

Grains contributed to around 9% of the overall GWP, with rice (4%) and wheat flour (5%) being the key hotspots. Most of the emissions for rice and wheat flour were produced at the farm level. Among legumes and meat substitutes, the boiled dry split peas had the largest impact (2%) in the basket's GWP, largely due to the energy use for cooking (63%).

The results for the environmental footprint of the 'Vegan' food basket should be compared and interpreted with caution largely due to its poor representativeness and the uncertainty about the most commonly consumed food items in each of its food categories. Given the high level of uncertainty regarding the composition of the 'Vegan' food basket, robustness of the results was tested through a sensitivity analysis (Figure 7). The commonly consumed foods in each of the food groups were assumed to be similar to those of the 'Vegetarian' food basket.

The sensitivity analysis confirmed the main trend that the 'Vegan' food basket had the lowest impact even after changing the basket composition. With the food groups composed of food items that were characteristic to the 'Vegetarian' diet, the GWP of the 'Vegan' food basket decreased by 155 kg CO2-eq.

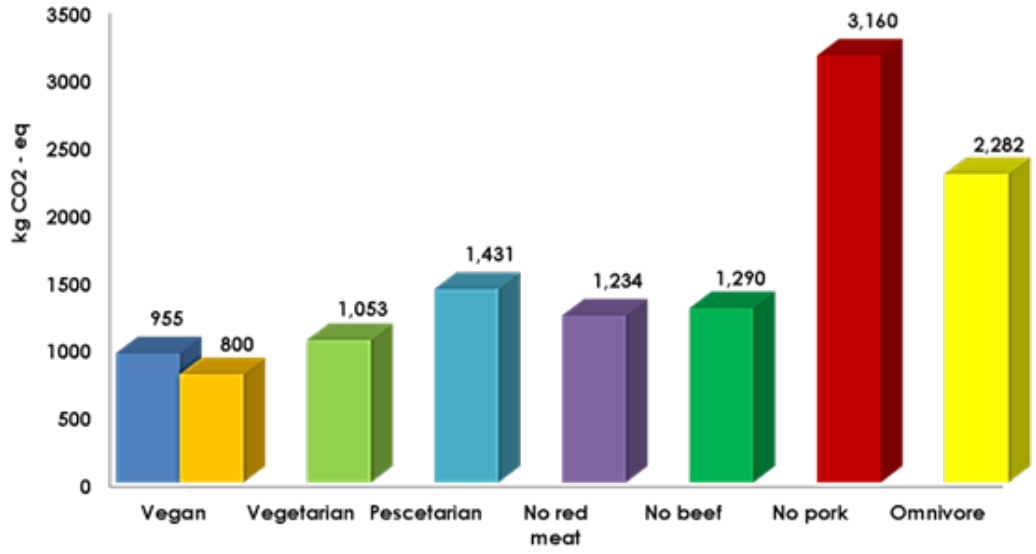


Figure 7. Sensitivity analysis of the 'Vegan' food basket.

3.1.2 'Vegetarian' food basket

The calorie-adjusted 'Vegetarian' food basket had the second lowest GWP (1,053kg CO_2-eq. which would equal to 2.9 kg CO_2-eq. a day). The primary environmental hotspot in the food basket was the 'dairy and egg' food group that contributed to over 50% of the overall GWP.

As depicted in Figure 8, eggs contributed to around 12% of the overall GWP. The high-impact dairy products included cheese (19% of total GWP), butter (15%) and to a lesser extent milk (6%). Most of the impact for eggs and dairy products was associated with the dairy farming. Dairy products such as cheese and butter had a higher impact due to the higher content of milk solids and fat which required larger volumes of milk during production. Given the large share of dairy products in the food basket, the cold storage for dairy and eggs contributed to around 3% of the overall GWP.

The vegetable food group contributed to over 10% of the GWP. Around 4.6% of the impact in the 'Vegetarian' food basket was associated with lettuce. Processed canned tomato contributed around 3.5% with large share of the impact originating from packaging.

Similar to the 'Vegan' food basket, the brewed coffee among all other beverages was one of the biggest hotspots (4%). Storage for juices and carbonated drinks accounted for around 2%.

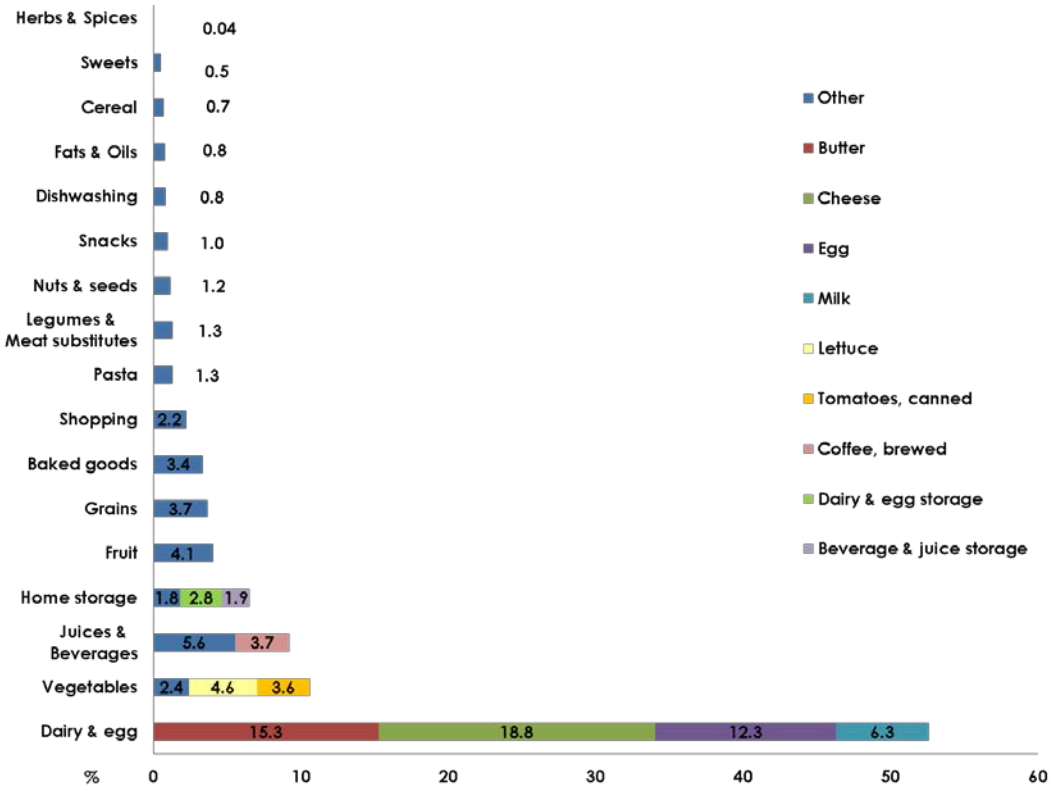


Figure 8. Key food groups and food items contributing to the environmental impact of the 'Vegetarian' food basket.

3.1.3 'Pescetarian' food basket

The 'Pescetarian' food basket ranked third with regard to the GWP level (1,431 kg CO_2-eq.). The overall GWP equaled to 3.9 kg CO_2-eq. per person per day. Dairy and eggs accounted for more than a third of the total GWP of the food basket. The largest contributor was butter (10%), followed by egg (10%), cheese (8%) and milk (6%).

Fish products contributed around a quarter of all the GHG emissions. Due to a higher share of tuna in this food group, tuna had a relatively larger impact than salmon. Most of the impact for canned fish originated from packaging and ranged from 25 to 40% of its impact. Salmon was assumed to be sourced from British Columbia, thus the transportation by air of the frozen fish accounted for around 40% of the GHG emissions. Farm-level emissions accounted for another 35%. Canned tuna was imported from Thailand and farming operations were the primary source of the overall emissions (54%). Baroni et al. (2007) also showed the relatively high impact of fish in the diet.

Similar to other food baskets, lettuce was a common hotspot within the vegetable food groups (9%) and the brewed coffee – among the beverage group (3%).

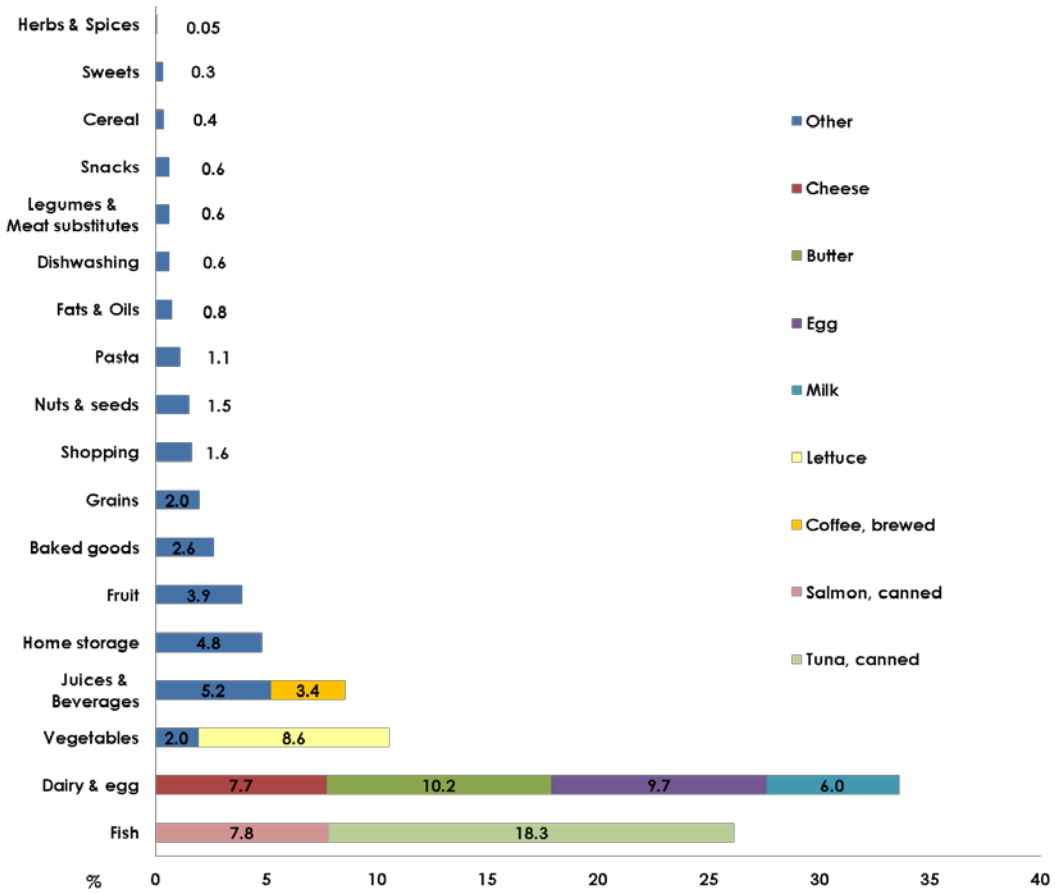


Figure 9. Key food groups and food items contributing to the environmental impact of the 'Pescetarian' food basket.

3.1.4 'No Red Meat' food basket

The 'No Red Meat' food basket had the third lowest GWP (1,234 kg CO_2-eq.). This translated to 3.4 kg CO_2-eq. per person per day.

Similar to the 'Vegetarian' and 'Pescetarian' food baskets, dairy and eggs had the largest contribution to the overall impact of the 'No Red Meat' food basket (39%). Butter was the leading source of emissions (17 %), followed by egg (15.5%) and milk (7%). Meat, particularly chicken, accounted for 12 % of the total GWP, while fish contributed to over 6% of GHG emissions. The key hotspot in the vegetable group was lettuce (8%).

Coffee was the largest hotspot among the beverages (3.5%), followed by orange juice (2.5%). Most of the impact in the orange juice life cycle was associated with the raw materials (10%)

and packaging (39%). Among storage-related emissions around 2% was allocated to dairy and egg refrigeration and 1.3% - to juices and beverages.

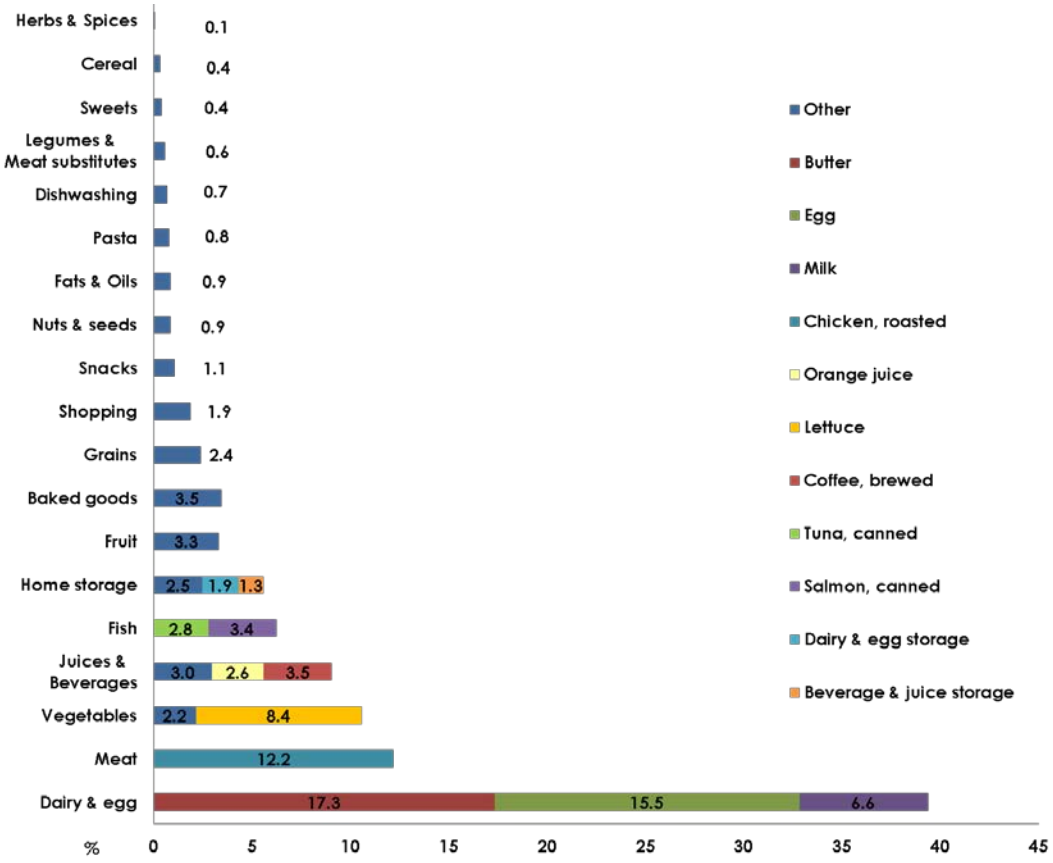


Figure 10. Key food groups and food items contributing to the environmental impact of the 'No Red Meat' food basket.

3.1.5 'No Beef' food basket

The 'No Beef' food basket accounted for 1,290 kg CO_2-eq. This would equal to 3.5 kg CO_2-eq. per person per day.

Similar to the 'Vegetarian', 'Pescetarian' and 'No Red Meat' food baskets, the dairy and egg products had the largest level of GHG emissions (36%) with butter accounting for 16.5%, cheese – 14% and milk - 6%.

Despite pork and chicken being consumed in similar amounts, pork accounted for around three times more GHG emissions (13%) than chicken (4.5%). The key source of emissions for both types of meat is farming operations and animal efficiency. Studies in other countries have

shown varying estimates of the impact related to the production of the two meat types, but generally supported the higher impact of pork (de Vries & de Boer, 2010; González et al., 2011; Goodland, 1997). Tuna and salmon were also consumed in similar amounts but the salmon contributed twice the amount of GHG emissions (4%), primarily due to air freight used in salmon supply chain.

Lettuce was a hotspot within the vegetable food group and brewed coffee contributed most to the beverage food group. They accounted for 8% and 3.5% of overall impact, respectively.

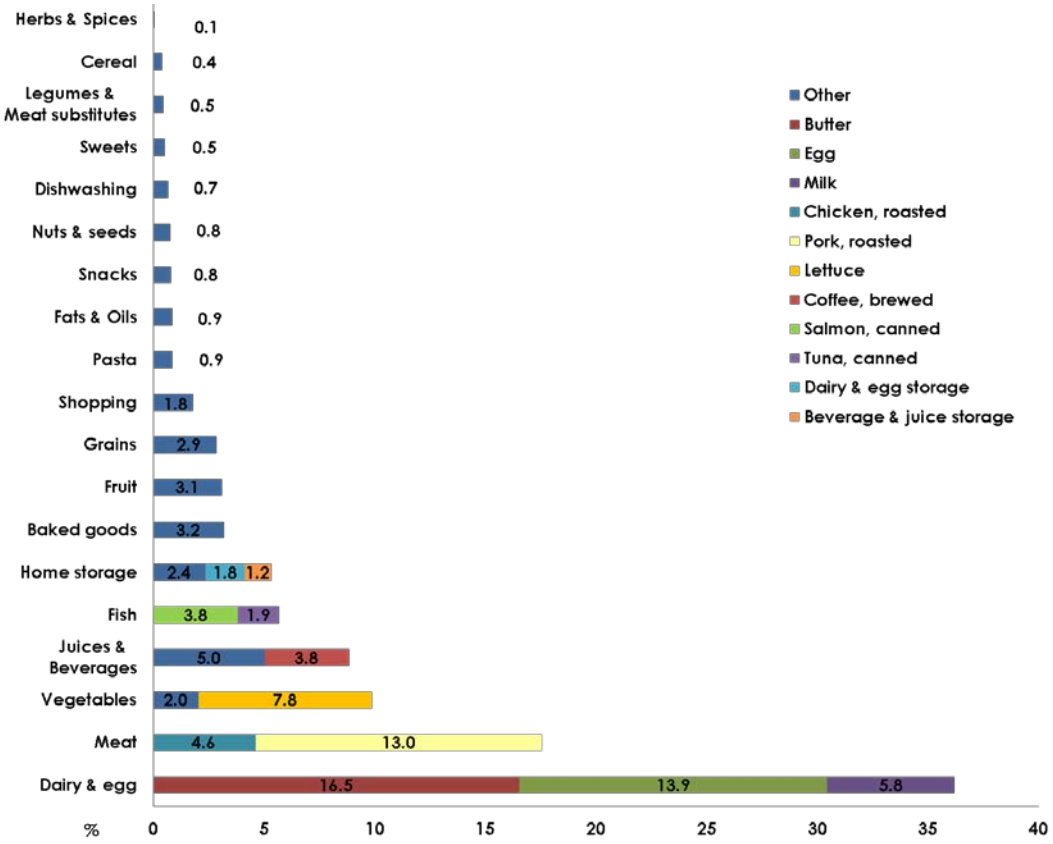


Figure 11. Key food groups and food items contributing to the environmental impact of the 'No Beef' food basket.

3.1.6 'No Pork' food basket

The 'No Pork' food basket demonstrated the highest GWP among all seven dietary patterns (3,160 kg CO_2-eq.). This equals to around 8.7 kg CO_2-eq. per person per day. The impact was dominated by meat, particularly beef (68%). Pork was mainly substituted by beef and to a smaller extent by chicken (Figure 12).

Similar to the findings of other diet-related studies, beef was the primary hotspot in the meat-based dietary patterns (Baroni et al., 2007; Carlsson-Kanyama & González, 2009; Hendrie et al., 2014; Muñoz et al., 2010; Saxe et al., 2013). This was largely due to the high volume of beef consumption among the Ontario population representing this dietary pattern, farm-level emissions from animals as well as from cultivation of feed, and inefficient conversion of raw weight to the cooked meat (WCRF, 2007).

Dairy had relatively lower contribution of around 13% with butter and egg accounting for over 5% of the total GWP each.

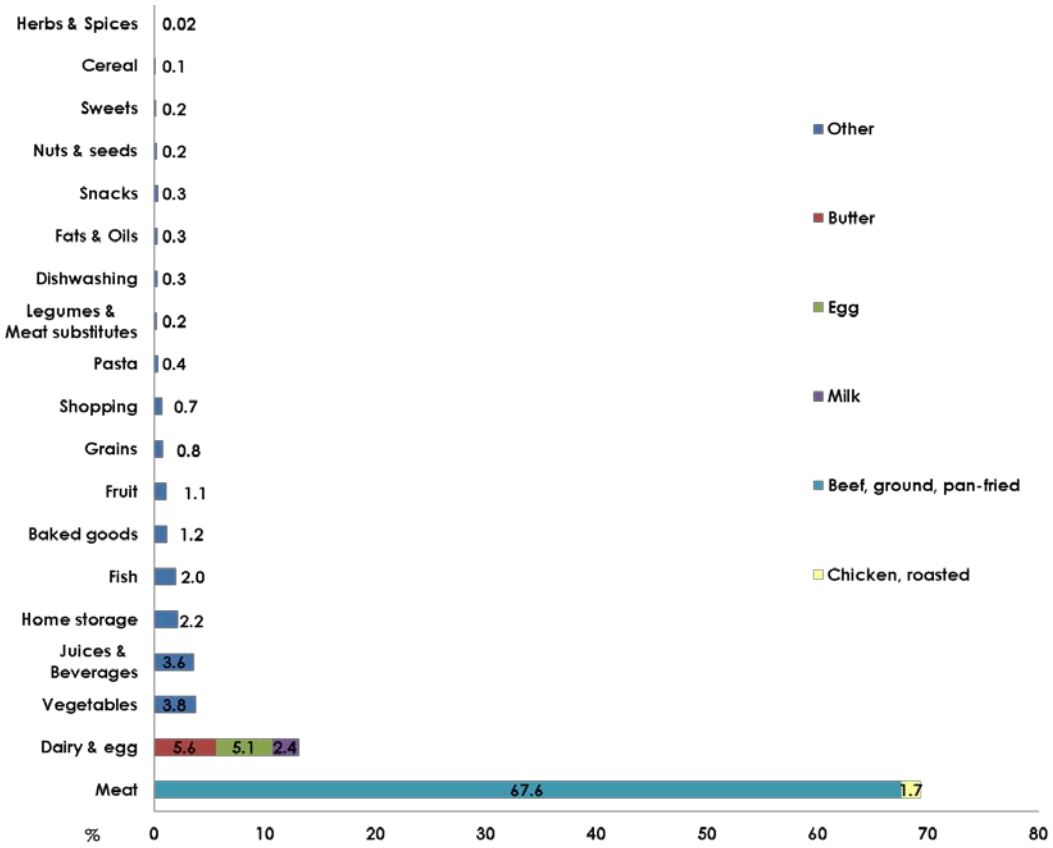


Figure 12. Key food groups and food items contributing to the environmental impact of the 'No Pork' food basket.

3.1.7 'Omnivorous' food basket

The examination of the dietary pattern with the second highest GWP (2,282 kg CO_2-eq. or 6.3 kg CO_2-eq. per person per day) revealed that, similar to the 'No Pork' food basket, beef was

the largest source of GHG emissions (48%). Other types of meat had a relatively smaller contribution of 3.4% (pork), 3.2% (mixed meat) and 1.6% (chicken).

Dairy and eggs accounted for over 20% of overall GWP. Vegetables accounted around 7.5% of the total impact with lettuce being the main hotspot (4%).

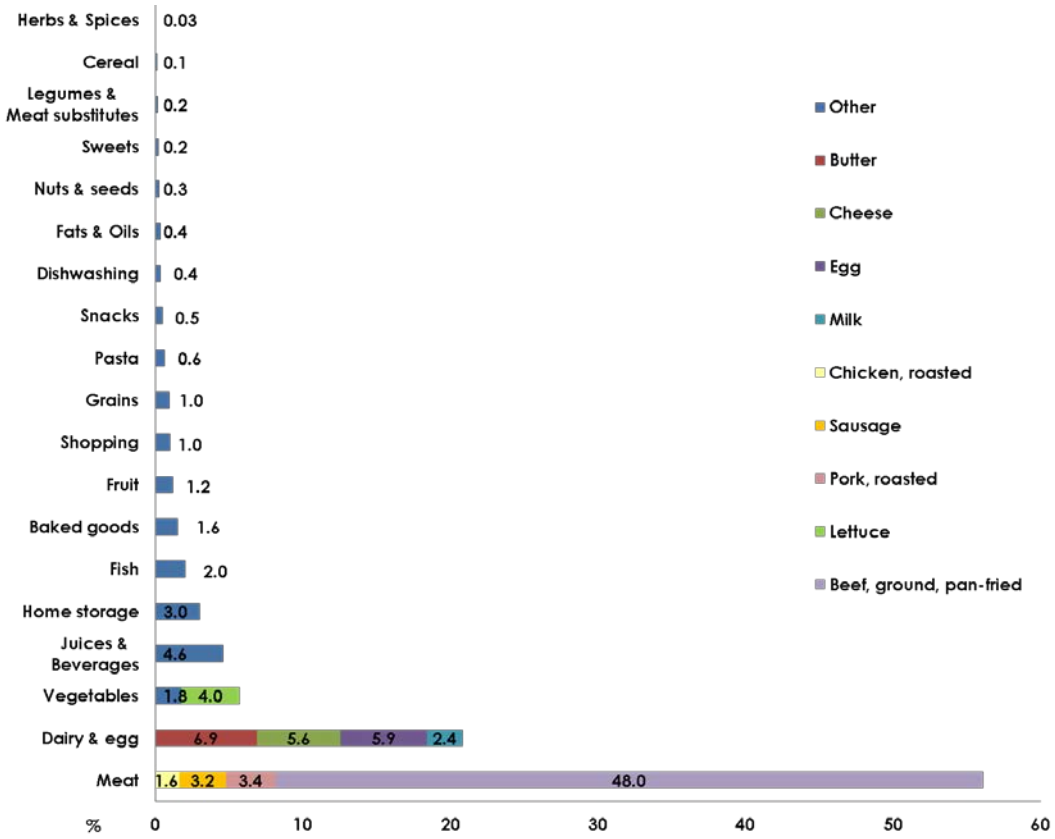


Figure 13. Key food groups and food items contributing to the environmental impact of the 'Omnivorous' food basket.

Examination of all seven food baskets showed that beef was the single food item with the highest GWP, which logically follows the findings of existing studies. Other high-impact foods included cheese, butter, egg, milk, and fish (salmon and tuna in Canada), which was similar to the findings of the European studies (Baroni et al., 2007; Tukker et al., 2011).

Greenhouse vegetables, particularly lettuce, had a significant impact which is comparable to the results of existing studies (Carlsson-Kanyama et al., 2003; Virtanen et al., 2011). Coffee was also found as one of the environmental hotspots by Saxe et al. (Saxe et al., 2013).

3.2 Sensitivity analysis

3.2.1 Functional unit

The sensitivity analysis tested the robustness of the results by changing the functional unit to 'protein-adjusted' and 'unbalanced' functional units (Figure 4). 'Unbalanced' functional unit refers to a food basket representing the typical intake of food within a preferable food pattern per person per year. The function of each basket was to supply a typical set of foods to one person throughout one year.

'Protein adjusted' functional unit refers to a food basket representing a particular dietary pattern and delivering an annual supply of recommended amount of protein per person. Thus, the function of these food baskets was to supply sufficient amount of protein to one person throughout one year.

The trend remained the same as in the comparison of the food baskets on the basis of the equalized energy intake. The 'Vegan' food basket had the lowest GWP except for the protein-adjusted functional unit, and the 'No Pork' food basket demonstrated the highest GWP among all seven dietary patterns regardless of the choice of the functional unit.

The 'Vegan' food basket had the third largest impact only on a protein basis. This was largely due to the low level of protein content in the initial unbalanced food basket and a substantial increase in the amount of food in order to balance the protein levels.

Due to the overall excess of protein in the animal-based food baskets, the protein content was reduced towards the recommended levels. Thus, the total GWP of protein-adjusted food baskets decreased by up to 50% relative to the unbalanced and calorie-adjusted versions of corresponding food baskets. Overall, the environmental performance of all the food baskets changed significantly based on various functional units. This trend is widely observed in other food-related studies (Kendall & Brodt, 2014), but has not been previously tested in the diet-related research.

3.2.2 Beef production

The contribution analysis indicated that beef was one the most important sources of GHG emissions in the meat-based food baskets. The sensitivity analysis tested the key assumptions made with regard to the beef production and consumption.

Beef was assumed to be supplied from a farm with traditional dry lot operations. The sensitivity analysis used the results from a farm using a different management practice to identify the potential change in the overall impact. The extended bale grazing was used as an alternative farming practice (Dias et al., 2015).

As shown in the Figure 14, the overall results did not indicate a significant difference from the baseline scenario. The farm-level emissions per kilogram of animal live weight were measured at 10.54 kg CO_2-eq. for the traditional dry lot operations, compared to 10.32 kg CO_2-eq. for the extended bale grazing scenario.

It was also assumed that beef was supplied from the Western provinces in Canada, particularly Alberta. Another scenario tested the assumption that the beef was supplied from an alternative location in the Northern Great Plains states, USA (Lupo, Clay, Benning, & Stone, 2013; Pelletier, Pirog, & Rasmussen, 2010). Without accounting for additional transportation, and changing the supply source only marginally increased the results. The changes did not affect the overall comparison between the seven food baskets. Thus, sensitivity analysis illustrated that regardless of the origins of meat and farming practices, The 'No Pork' and 'Omnivorous' food baskets maintained the highest GWP levels, while beef remained the largest hotspot in the food consumption.

The same trend is seen globally. According to FAO, its estimated contribution to the GWP is around 18% (de Vries & de Boer, 2010).

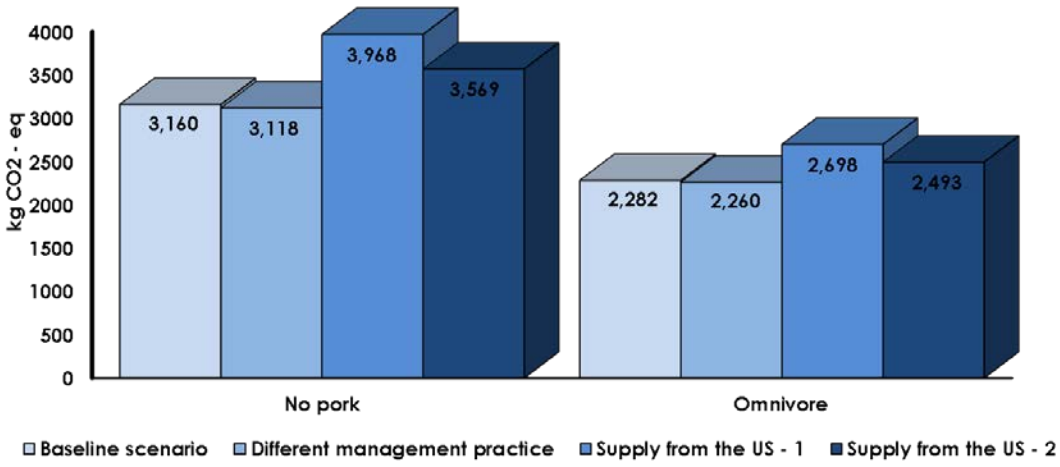


Figure 14. Sensitivity analysis on the assumptions with regard to the beef production: production practices and origins.

3.3 Scenario analysis

3.3.1 Nutritionally balanced, climate friendly and socially acceptable food baskets

Adjusting the diets so that consumed amounts followed the dietary guidelines and choosing climate-friendly food items reduced the overall GWP of each dietary pattern, with exception of the 'Vegan' dietary pattern, which increased by over 17% (Figure 16). This was primarily caused by the lower calorie and protein content in the original unbalanced food basket, which was half the recommended level, and a lower intake of all the key food categories, at around 60% of recommended values (Figure 3; Table 3). Thus, increasing the content of the basket and adjusting the calories resulted in the overall increase of GWP. There was also a great uncertainty about the 'Vegan' food basket composition due to limited CCHS 2.2 data, which could have affected the overall results of nutritional assessment and subsequent LCA.

The substitutions for high-impact foods in the scenario analysis were based on the results of the contribution analysis in the LCA (Figure 15). Substitutions were chosen primarily for protein sources. High-protein high-impact foods (cheese, beef, salmon, tuna, pork, etc.) were substituted by either high-protein foods with relatively lower impact (tofu, soybeans, peanuts and other) or foods with lower protein content and lower GWP (snap beans, green peas), particularly in the food baskets with excessive consumption of protein.

Figure 16 demonstrates the GWP reduction potentials for each dietary pattern, which ranged from 5 up to 34%. The largest reduction occurred in the 'No Pork' and 'Omnivorous' food baskets that initially demonstrated the highest GWP. The GWP was reduced by more than a third by increasing the consumption of fruit and vegetables, grain products and milk, and reducing consumption of high-impact products such as meat, butter, cheese and egg by half.

The potential reductions for the 'Vegetarian' food basket resulted in around over 5%, primarily after reducing consumption of dairy products to recommended levels and lowering the share of cheese by half. The reduction potential is modest potentially due to lower content of the key food groups in the original food basket (Table 3). Substantial increase in the amount of grains, meat alternatives, fruits and vegetables could have potentially offset the potential GWP reduction.

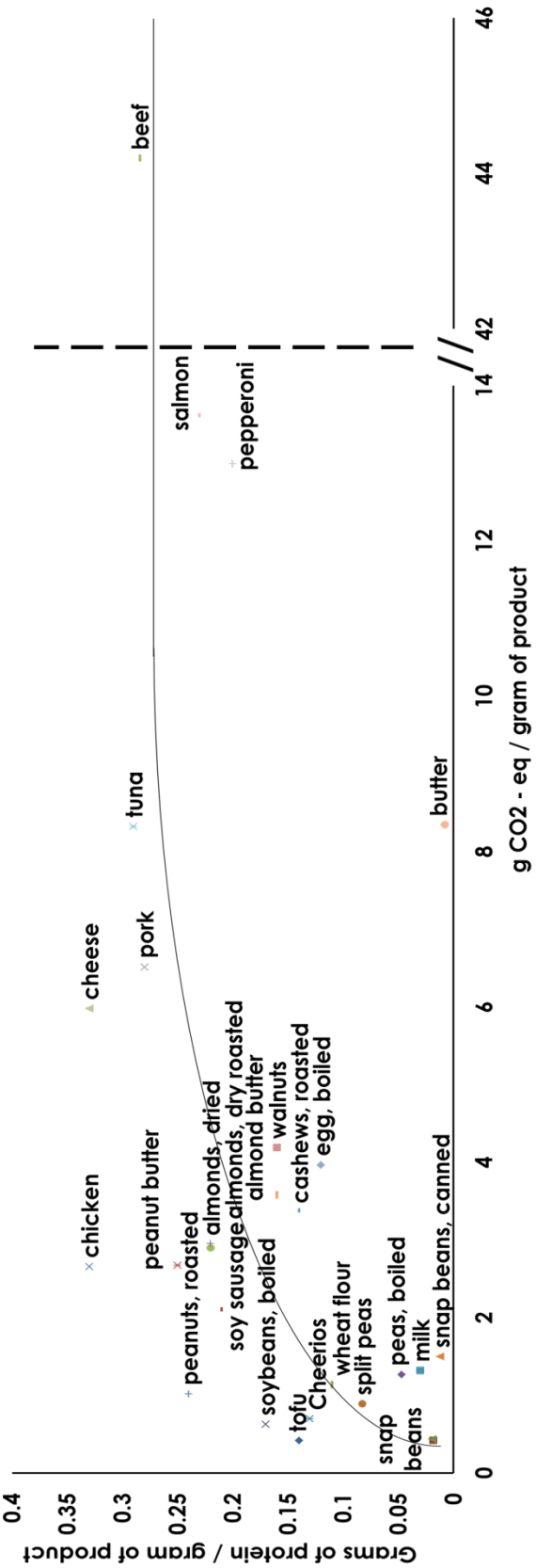


Figure 15. Protein sources and corresponding GWP, calculated in LCA.

The GWP of the 'Pescetarian' food basket decreased by 11%, largely after reducing fish, cheese and egg intake by half. The GWP of the 'No Red Meat' food basket decreased by less than 5%. The most important reduction was due to the lower meat and egg intake. The reduction potential was modest due to a relatively lower GWP of poultry, which was the main meat choice in the original food basket. The 'No Beef' food basket improved its GWP by over 12% largely by minimizing the intake of pork, poultry and eggs.

Despite increasing the intake of high-impact food items such as milk, rice and fish, and increasing the content of grains, fruits and vegetables in most of the food baskets, the overall GWP substantially decreased.

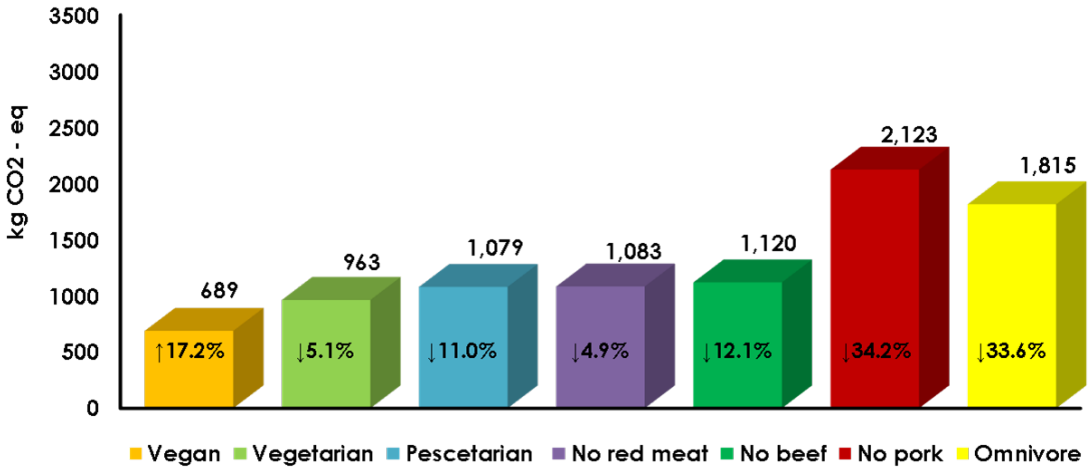


Figure 16. Scenario analysis: potential reduction in the GWP from switching to nutritionally balanced, climate friendly and socially acceptable food baskets.

Current research generally supports the idea that nutritionally optimal dietary patterns have a lower environmental footprint. Thus, Trolle and coworkers (2014) suggest the reduction potential of 4% for the recommended Danish diet. Healthy Nordic diets proposed by Saxe and coworkers (2013) suggest 7-8% impact potential reduction in comparison with the baseline Danish diet. The reduction potential is almost identical regardless of whether the Danes choose to follow the Nordic Nutritional Recommendations or a New Nordic Diet developed by the OPUS project (Saxe et al., 2013).

Complying with the Finish nutritional guidelines is likely to reduce the diet-related GWP by 16% due to consumption of more plant-based foods, lower share of animal-based foods and reduction of milk consumption to 60% of the current level (Risku-Norja et al., 2009). Transitioning to a healthier diet in Germany can potentially result in around 12% reduction of

diet-related GHG emissions (Meier & Christen, 2012a). A similar reduction is possible in the Netherlands, while in Finland a healthy diet can contribute to up to 16% GWP reduction (Risku-Norja et al., 2009; van Dooren & Aiking, 2014). Transitioning from a typical North American diet to a healthy Mediterranean diet resulted in 60% reduction potential (Barilla et al., 2013).

In individual cases, the diets that were formulated based on dietary recommendations have not resulted in considerable reduction of the overall impact (Tukker et al., 2011), whereas in France the impact increased by up to 22% among men (Vieux et al., 2013).

The difference in the reduction potentials is related to the impact of the baseline dietary pattern as well quantitative and qualitative dietary recommendations in a corresponding country. Another important factor is the extent to which the population complies with the recommendations. For example, in the case of a semi-vegetarian diet in the Netherlands which combines the traditional vegetarian and the recommended omnivorous diet, the resulting GWP indicates a relatively modest reduction potential (van Dooren et al., 2014).

The food baskets were intentionally modified in the scenario analysis to reduce the high-impact food consumption. Thus it might seem ambiguous whether the reduction potential stems primarily from adopting the dietary recommendations or minimizing the content of high-impact food items. However, studies have shown that the reduction potential improved. Thus, the GWP reduction potential increased from 4% to up to 23% in the recommended and climate friendly diet in Denmark (Trolle et al., 2014). According to Saxe et al. (2013), the reduction potential also improved (from 7% up to 19%) after partially substituting high-impact beef with other types of meat.

3.3.2 Electricity mix

The Ontario electricity mix (2013) had a relatively low carbon footprint. The scenario analysis was performed to determine the potential changes in the environmental impact of the food baskets based on various sources of electricity.

Mallia & Lewis (2013) showed that nuclear power had the lowest life cycle GHG intensity among other electricity sources in Ontario. Thus, the best case scenario was based on electricity sourced 100% from nuclear power. The Swiss electricity grid, primarily dominated by hydro power and nuclear energy, was chosen as another alternative. The use of these alternative electricity sources did not affect the overall comparison of the seven food baskets and only

marginally changed the overall GWP of individual food baskets. The GWP improved on average by 7% in the best case scenario and increased by around 1% in case of the Swiss electricity mix.

Using US electricity mix or electricity sources based 100% on coal increased the overall GWP of all the food baskets and slightly changed the trend compared to the baseline scenario. Coal-based electricity increased the GHG emissions of the food baskets by 25 to 70%, while the electricity mix similar to the US grid increased it by around 16 to 47%. 'Vegan' food basket demonstrated the lowest GWP but increased above the levels of the 'Vegetarian' diet for scenarios for the coal-based and US electricity mix.

Overall, the choice of electricity source did not significantly affect the overall trend and comparison of the seven food baskets. However, the environmental performance of each food baskets worsened in cases of US electricity mix and coal-based electricity mix. Proportionally, the lower impact diets were impacted more than the higher impact diets.

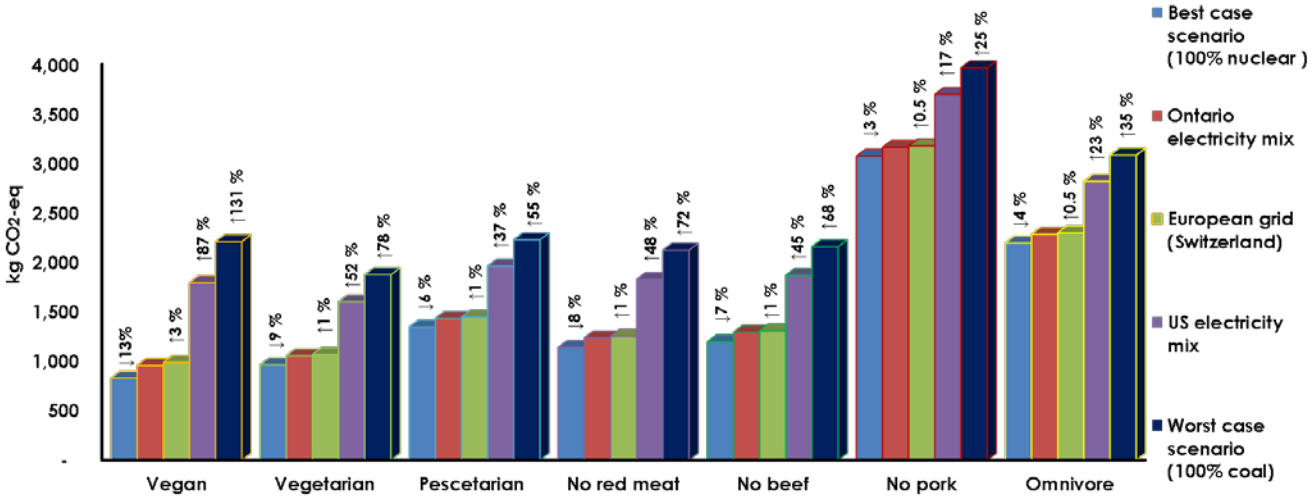


Figure 17. Sensitivity analysis on the electricity mix: change of electricity mix from the cleanest to least preferable sources.

3.3.3 Reduction of avoidable food waste at a household level

The scenario analysis results suggested that, depending on the dietary choices, the environmental impact of avoidable food waste in the households of Ontario ranged from 9.5 to up to around 15% of the total diet-related GWP. Apart from inefficiencies along the supply chain, household waste accounted for the largest share of contribution to emissions (10%).

The food waste contributed a significant part of the impact due to increased resource intensity and associated emissions. The overall demand for products was higher than its actual consumption. This implied that there were more greenhouse gases emitted and resources used than was needed for consumption. Scenario analysis was performed to measure the reduction potential resulted from reducing the food waste. Only avoidable food waste at the household level was used for the scenario analysis.

The first scenario assumed that the Ontario residents could reduce their avoidable food waste by around 20% with small behavioral changes. The behavioral changes could be promoted through education programs about the impacts of food waste on the food security and associated environmental impacts. Thus, 20%-reduction in avoidable food waste would result in around 2.7-3.6 % decrease in the overall GWP of food baskets.

If Ontario residents cut down on their avoidable household food waste by half, it would result in a better environmental performance of each dietary pattern. The impact reduction would range from 5 % up to around 8% of the overall GWP. The effect of reducing the food waste would be most profound within the 'No Pork' food basket (7.8%).

The current research supports the findings and recognizes the notable contribution of food waste to the overall environmental impact (Friel et al., 2013). Thus, Munoz and coworkers (2010) demonstrated that, although food waste at households is not a primary environmental hotspot, it is comparable to the footprint of wholesale and retail stage of the life cycle with regard to climate change impacts.

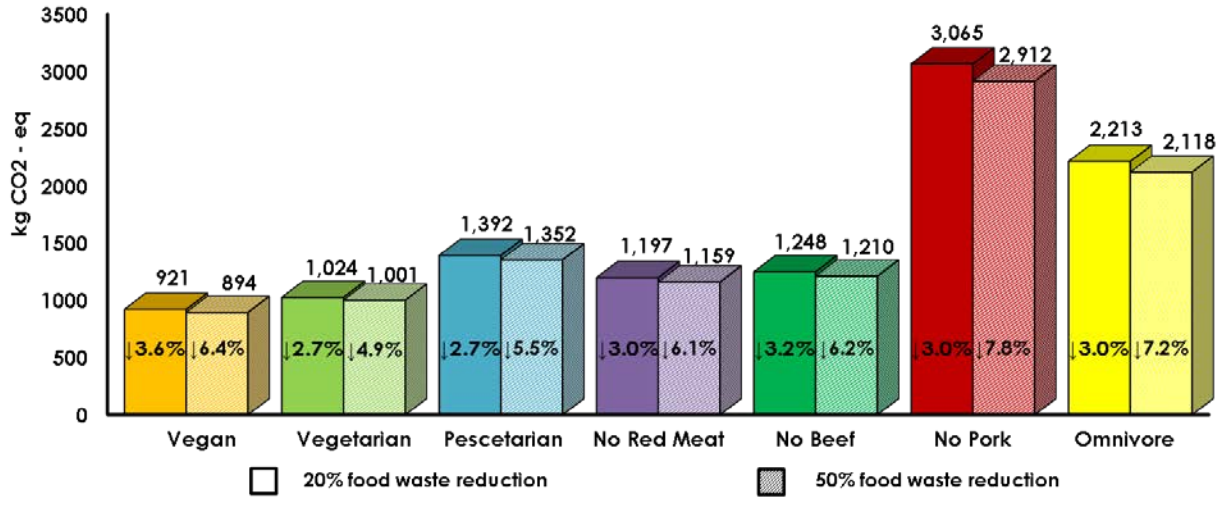


Figure 18. Scenario analysis: reducing avoidable food waste at a household level by 20% (left) and 50% (right) and quantifying potential improvement of the carbon footprint.

3.3.4 Storage

The food storage at the household level was found to be one of the key hotspots in the 'Vegan' and the 'Vegetarian' food baskets, primarily because of relatively lower GWP of the original baskets. Although the impact from refrigeration was assumed to be equal among all the food baskets, proportionally it affected these two food baskets relatively more. And hence the greater impact of electricity.

One of the potential measures that could be taken by Ontario population was changing refrigerators to energy-saving Energy Star refrigerators. Overall, this reduced their GWP on average by 17 kg CO_2-eq. Proportionally, the impact reduction was more pronounced in the 'Vegan' and the 'Vegetarian' food baskets (1.8% and 1.6%).

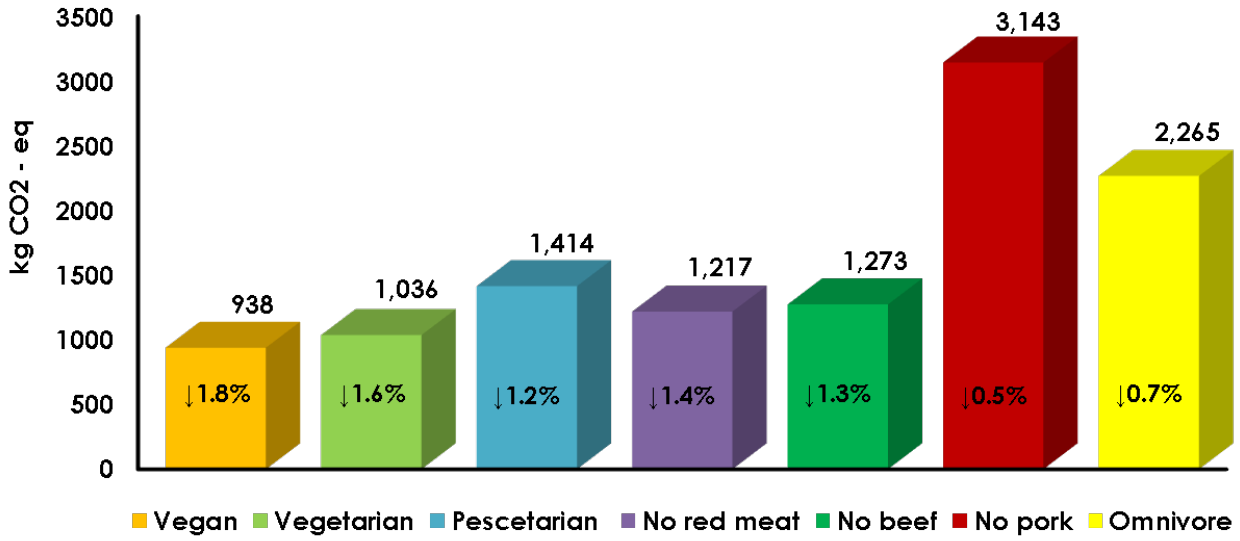


Figure 19. Scenario analysis: switching to the Energy Star refrigerators and quantifying potential improvement of the carbon footprint.

Summary of key findings

The results showed that around 90% of Ontario residents follow some form of meat-based diet, with 30% of the population following the 'Omnivorous' dietary pattern.

The GWP associated with the current dietary patterns ranged from 955 to 3,160 kg CO_2-eq. The 'Vegan' dietary pattern demonstrated the lowest environmental impact, while the dietary pattern excluding pork ('No Pork' dietary pattern) had the highest GWP. The key sources of emissions were beef, dairy products, egg, salmon, tuna, lettuce and coffee.

Overall, based on food choices characteristic to the patterns on a single day, all seven dietary patterns were nutritionally unbalanced according to the Canada's Food Guide. They contained excessive amounts of protein, insufficient intake of calories and inadequate consumption of key food groups such as milk and alternatives, grain products, fruit and vegetables and meat and alternatives, including fish.

Modeling of the nutritionally balanced, environmentally preferable and socially accepted dietary patterns revealed high impact reduction potentials among all dietary patterns, except 'Vegan' dietary pattern. The measured reduction potentials ranged from 5% ('Vegetarian' and 'No Red Meat' dietary patterns) to around 34% ('No Pork' and 'Omnivorous' dietary pattern).

Among all the measures that could be taken by the consumer in order to mitigate the environmental footprint, switching to a nutritionally balanced diet simultaneously substituting high-impact food items to low-impact alternatives would result in the highest reduction potential. This would not only mitigate the environmental impact but also ensure health among the population.

CHAPTER V: DISCUSSION & CONCLUSION

This chapter aims at interpreting and analyzing the findings of the conducted LCA in order to determine the environmental impact associated with the current dietary patterns in Ontario.

The results of the study provided a baseline for benchmarking Canada against other countries involved in diet-related research and for initiating further research in the field. The discussion of the results also aims at describing the synergy of the nutritional and environmental components in the sustainability assessment of the food consumption and providing recommendations for formulating healthy, environmentally friendly and socially acceptable dietary patterns.

1. Benchmarking Canadian dietary patterns

The results of the present study allow benchmarking Canada against Europe, USA, Australia and developing countries with regard to the environmental performance of dietary patterns. Results are within the same order of magnitude as in other countries, but with slight variations.

Comparing to **European countries**, the GWP of the 'Omnivorous' dietary pattern is generally higher than the European average as well as estimates in Finland, Denmark, the Netherlands, Germany, Spain and France (Table 4). Compared to UK, the estimate is similar or notably lower, depending on the data source. The overall impact of a healthy 'Omnivorous' diet is similar to Denmark and Germany, whereas in Finland and the Netherlands the diet scored better.

As shown in Table 5, the 'Vegan' dietary pattern scored best in Ontario and Germany, with the GWP being 50% lower than in Finland and 3 times lower than in the UK. The GWP of the 'Vegetarian' diet is the lowest in Ontario (Table 6). The estimates are higher in Germany and in the UK by around 50% and 100%, respectively.

Overall, the US estimates are higher than the Canadian values. The 'Omnivorous' diet in the **USA** has a similar performance as in Ontario, which is only marginally lower. The GWP of the 'Vegetarian' diet in the USA is over 80% higher than that in Ontario, while the GWP of the 'Vegan' diet is over 2.5 times higher.

Both the unbalanced and a healthy 'Omnivorous' diets in **Australia** were associated with around 2 times higher GWP than Ontario.

When comparing to the developing countries, particularly **India**, the difference in the GWP is striking. India had the lowest estimates for both the healthy 'Omnivorous' and healthy 'Vegetarian' diets among all countries.

The GWP of the diets across various countries differs potentially due to variations in traditional diets, food preferences within identical dietary patterns, choices of commonly consumed foods and food basket composition, food availability as well as production and import statistics, local production practices and technologies.

Table 4. Comparison of the Global Warming Potentials of the 'Omnivorous' dietary pattern in Ontario and other countries. The lighter color reflects a lower value, the darker color indicates a higher value than in Ontario.

kg CO_2-eq.	Omnivorous unbalanced	Omnivorous calorie-adjusted	Omnivorous healthy	Reference
Ontario	2,734	2,282	1,815	
Finland	1,692	-	1,421	Risku-Norja et al., 2009
	2,811		-	Virtanen et al., 2011
India	-	-	351	Pathak et al., 2010
Denmark	1,820	-	1,748	Trolle et al., 2014
EU (27)	-	1,390	-	Tukker et al., 2011
Germany	-	2,050	1,810 - 1,820	Meier & Christen, 2012a
Netherlands	1,285	-	1,121	van Dooren & Aiking, 2014
UK	2,701	-	-	Berners-Lee et al., 2012
	3,212			Hoolohan et al., 2013
Spain	2,100	-	-	Muñoz et al., 2010
USA	2,780	-	-	Kim & Neff, 2009
Australia	5,293	-	3,979	Hendrie et al., 2014
France	1,522	-	-	Vieux, 2012

Table 5. Comparison of the Global Warming Potentials of the 'Vegan' dietary pattern in Ontario and other countries. The lighter color reflects a lower value, the darker color indicates a higher value.

kg CO2-eq.	Vegan unbalanced	Vegan calorie-adjusted	Vegan healthy	Reference
Ontario	587	955	689	
Finland	879	-	-	Risku-Norja et al., 2009
Germany	-	960	-	Meier & Christen, 2012a
UK	1,876	-	-	Berners-Lee et al., 2012
USA	1,530	-	-	Kim & Neff, 2009

Table 6. Comparison of the Global Warming Potentials of the 'Vegetarian' dietary pattern in Ontario and other countries. The lighter color reflects a lower value, the darker color indicates a higher value.

kg CO_2-eq.	Vegetarian unbalanced	Vegetarian calorie-adjusted	Vegetarian healthy	Reference
Ontario	1,015	1,053	963	
India	-	-	239	Pathak et al., 2010
Germany	-	1,560	-	Meier & Christen, 2012a
UK	2,113	-	-	Berners-Lee et al., 2012
USA	1,850	-	-	Kim & Neff, 2009

Similarly to unique dietary patterns in other studies, such as 'Ruminants excluded' and 'High red meat' diets (Risku-Norja et al., 2009; Kim & Neff, 2009), a few new dietary patterns emerged from the present study. The 'Pescetarian', 'No Red Meat', 'No Beef' and 'No Pork' dietary patterns are variations of the meat-based diets. These dietary patterns are well represented in the Canadian context however do not have prototypes in other countries. Thus, the comparison of the results was not feasible.

Overall, the present study positioned the dietary patterns in Ontario relative to the environmental performance of dietary patterns in European countries, USA, Australia and India; and introduced four new variations of the high-impact meat diets (i.e. 'Pescetarian', 'No Red Meat', 'No Beef', 'No Pork') for further comparison.

2. Food as an environmental hotspot

The results of contribution and sensitivity analyses of the present study corroborate the findings of the diet-related LCA studies in other countries. As expected, beef was found to be a single food item with the highest impact and the key contributor to the GWP. Apart from contributing to climate change, livestock, particularly beef, is also believed to compete for food and land, and lead to acidification and eutrophication (de Vries & de Boer, 2010; Pimentel & Pimentel, 2003).

Over the past fifteen years the beef industry in Canada has expanded and is expected to grow even further (FCC, 2015). Consequently, the gross GHG emissions associated with the beef production have increased by over 40% and are likely to rise if the trend continues (Beauchemin et al., 2010). One of its key strategic goals is to enhance the demand for beef (FCC, 2015).

One of the widely proposed strategies to minimize the environmental impact from livestock sector is to reduce consumption of high-impact beef and substitute it with meat alternatives

that exhibit a lower GWP such as poultry, pork or legumes (BCFN, 2014; de Vries & de Boer, 2010).

Reducing the leading cause of diet-related emissions in Ontario might become a challenging quest. Even though the per capita beef consumption declined over the years, the domestic demand for beef is strong and growing (FCC, 2015). The decline may be attributed to increasing meat prices, a growing variety of competing protein sources, increasing preference of other dietary patterns and culturally-diverse demographics. Canadian consumers express their preference of beef over other meat types by being willing to pay higher prices for the product (FCC, 2015). As results of this study showed, over 60% of the Ontario population lead a dietary lifestyle heavily dependent on beef consumption ('No Pork' and 'Omnivorous' dietary patterns). Preference for beef as a choice of meat not only stems from the nutritional needs but is also likely to be determined by wealth of population, the Northern location of Canada, beef texture and taste as well as culture and traditions (Richardson, Shepherd, & Elliman, 1993).

Consumers are reluctant to change their meat consumption for a wide number of reasons, including enjoyment from eating meat, unwillingness to change eating habits, and a strong perception, especially among male population, that humans were meant to eat meat (Lea & Worsley, 2003). In case of dietary changes, particularly reduction in meat consumption, consumers are also more likely to do so primarily out of health concerns as opposed to environmental considerations (Joyce et al., 2012). For example, increasing adoption of vegetarian and vegan diets has been shown to be largely related to health and ethical motives (Fox & Ward, 2008). Thus, there is a strong potential for health practitioners to promote the environmentally friendly dietary change.

Given the contrasting interests of the beef industry and environmental policies, as well as significance of the food sector both for the economy and the environment, there is a need for clear policy targets in the agri-food sector. The priority should be not only to improve the GHG intensity of the sector, but also to minimize the production of beef, as a whole.

As an effort to educate the consumer about the environmental implications of beef production and consumption, environmental labeling of consumer products would promote sustainable and informed food choices in Canada. Along with reducing consumption of beef, consumers are advised to minimize the consumption of other high-impact foods such as meat, cheese, eggs and foods that are likely to be transported by air or grown in a greenhouse.

3. Protein, Health & Environment

The results of the nutritional assessment suggest protein overconsumption among Ontario's population (Figure 3). The same trend is noted across Europe and USA (de Marco & Velardi, 2014; Fulgoni, 2008).

Surprisingly, the nutritional assessment of eating habits of Canadians suggests that protein intake among Canadians is within acceptable range (Garriguet, 2004). The same report, however, states that the average meat consumption meets the recommended number of servings within the protein food group. This assessment, interestingly, did not consider the number of servings of other protein-rich foods such as fish, legumes, eggs, nuts and seeds, accounting for up to 40% of protein intake in a diet and all contributing to the excess amount of protein.

González et al. (2011) showed that the protein delivery efficiency of plant-based foods can be higher than that of the animal-based foods, particularly in case of soybeans, peas and oats. Plant-based foods also supply most of the nutrients that come from the animal-based foods. According to González et al. (2011), the consumption of animal foods is often advocated due to their high iron and B12 vitamin content. While iron can be sufficiently supplied from other plant sources such as green leafy vegetables, grains and legumes, B12 vitamin can be supplied by supplements or a modest amount of animal-based foods in our diet (González et al., 2011). Thus, the plant-based proteins can be a valid and nutritionally adequate alternative to and environmentally preferable choice of protein. Meanwhile, the primary source of the protein in current dietary patterns in Ontario remains animal-based, reaching up to 80% of the total consumed protein. Misconception about the intake requirements and the sources of the protein is one of the potential explanations of the protein overconsumption (Macdiarmid, 2013).

There is strong evidence that the excessive protein in our diets is harmful to the environment. It is also complemented by the increasing number of recent studies suggesting that excessive protein is harmful for health and is linked to a number of NCDs (Barnard et al., 1995). The World Cancer Research Fund has set a recommendation for red meat consumption within the meat-based dietary patterns at 26 kilograms per year, with most of it, if any, in unprocessed state (WCRF, 2007). The public health goal is an annual maximum of 15.6 kilograms of red meat per person (WCRF, 2007). In Ontario, red meat consumption is alarmingly high – more than double the recommended level, with beef being a primary choice of meat.

Overconsumption of food in general has been shown to be neither healthy nor good for the environment (Friel et al., 2013). Consuming larger amount of food than is required for sustaining life and health is associated with a higher demand for food and, consequently, higher resource intensity and related emissions. Overconsumption of food might also jeopardize food security by diverting food and resources to more affluent groups of population. With regard to health, the consumption of food above one's energy requirements is shown to be linked to obesity and other NCDs (Friel et al., 2013).

It is apparent that protein-dense foods have a considerable impact on health and environment. At the same time, the Canadian nutritional guidelines seem to inherently promote their overconsumption. Along with the recommended daily protein intake, Canada's Food Guide also sets the required number of servings for milk, meat and their alternatives. Given that the recommended protein intake is not as effectively communicated to the general public as the Food Guide, the average population is likely to reach out for more obvious protein sources such as meat, eggs, milk and cheese to meet healthy eating guidelines, which directly correlates to a higher GWP of our diets.

A strong lobbying power of dairy and beef industry in Canada is likely to take a toll on environment and public health (Burgess, 2013). Active promotion of protein-rich foods has been making its way to the national dietary guidelines in Canada and around the world (Nestle, 1993 & 2010; Schwartz, 2012). Thus, nutritional adequacy is not an exclusive factor in formulating current dietary recommendations.

Consequently, the dietary guidelines and the way they are established presented and communicated to the public are partially responsible for overconsumption of protein and increased levels of GWP among the common Ontario diets. This establishes one of the key links between nutritional and environmental components of the diets and provides one of the main opportunities for reducing impact related to food consumption.

4. Is a healthy diet environmentally friendly?

The current dietary guidelines primarily focus only on the health implications of the diet, disregarding the impact on sustainability. The findings of the present study and existing literature suggest that there is a variety of alternative dietary patterns that offer a healthier and more environmentally friendly eating.

The combinations of healthy and eco-friendly food choices also emerge as new dietary patterns. In response to increasing awareness of the environmental implications of our dietary choices, terms such as 'demitarian' and 'flexitarian' diets gain popularity (BCFN, 2014; de Marco & Velardi, 2014). 'Demitarian' diet stands for the practice of reducing meat and fish consumption by half on an individual level based on the environmental motives, whereas a 'flexitarian' diet represents a flexible form of a vegetarian diet, which does not completely eliminate animal-based products but rather minimizes their consumption and replaces them with increased amounts of plant-based foods (BCFN, 2014).

Adoption of a healthy diet is primarily guided by the national dietary recommendations. Sustainability of the diets is often arbitrary and open to interpretation. The introduction of sustainable dietary guidelines is needed to insure sustainability of the food consumption. The idea of sustainable dietary guidelines has been circulating for over three decades, however has not resulted in a fruitful discussion between scientific community and the government (Joan Gussow & Clancy, 1986; Gussow & Clancy, 1999). Science has also advanced since then and now presents more compelling evidence in favor of sustainable nutritional guidelines.

Thus, Friel and coworkers (2013) modified existing dietary recommendations to form a healthy and sustainable food basket, which was used to advise Australian policy makers to adjust the national dietary guidelines accordingly and the public to adopt an eating habit that is healthy for them and the environment. In the USA, the 'My Plate My Planet' organization and the Science Advisory Committee have provided the USDA and US Department of Health and Human Services with a report based on the latest diet-related research and advocated for including sustainability criteria in the process of updating the U.S. Dietary Guidelines 2015 (Dietary Guidelines Advisory Committee, 2015; My Plate My Planet, n.d.).

Incorporating findings on the food and diet-related sustainability research in the dietary guidelines would ensure the synergy of human and environmental health. This initiative would also greatly affect the future of the nutrition policies and various food programs, including the School Lunch programs. This illustrates the importance of the up-to-date sustainability research and the nexus of public health and environmental research.

Thus, development of sustainable dietary guidelines should be also supported in Canada. To ensure their development, collaboration of nutritionists and environment professionals should be facilitated in research institutions and on a federal level. One of the ways to apply them would be reinforcement of environmental product labeling along with the nutritional labeling as

well as introduction of environmentally friendly menu options in restaurants and school lunches. Thus the modified guidelines and labels will help assist Canadians in making healthy and environmentally sound choices.

5. Sustainable versus climate-friendly

Sustainable dietary guidelines facilitate adoption of a healthy and low-impact diet. The present analysis results do not allow assessing a comprehensive environmental impact of current dietary patterns in Ontario due to a narrow focus on GWP, which is one of the key limitations of the present analysis. Although the findings provide an insight into the carbon footprint of current consumption patterns and produce climate friendly recommendations, a comprehensive analysis requires assessment of an array of impacts associated with food consumption.

The impacts that are pertinent to a particular geographical location should be considered in the analysis to reflect true diet-related environmental repercussions. Given the accelerated eutrophication occurring in the area of Niagara and Welland rivers (Diamond, 2011) and Lakes Erie and Ontario (Environment Canada, n.d.; Murphy, 2014), eutrophication potential needs to be considered in future analysis. Due to the limited data availability, eutrophication potential along with a number of other important impact categories was not included in the present analysis.

Van Dooren and Aiking (2014) suggested that consuming a healthy diet results not only in a lower GWP, but also in land use improvements. Wolf and coworkers (2011) found that the WHO-recommended diet has a lower contribution to resource depletion, climate change, ozone depletion, human toxicity, terrestrial acidification, freshwater eutrophication and photochemical oxidant formation, but a higher ecotoxicity impact due to increased pesticide use required for cultivation of larger amounts of nuts, fruits and vegetables. These assessments present a more accurate and complete evaluation of sustainability of various dietary patterns.

Moreover, the concept of sustainability is multidimensional and focuses not only on the environmental impacts, but also on society and economic prosperity. There are a few sides to the social component of sustainability. One of them is human health which has been addressed in the present study and in the literature.

The proposed sustainable guidelines should also be socially acceptable. This would primarily imply maintaining the current food choices. The present study proposed dietary modifications maintaining all seven dietary patterns, commonly consumed foods and reducing high-impact

foods by no more than 50%. Van Dooren and Aiking (2014) proposed a healthy and environmentally friendly diet that resembled the dietary pattern of the Dutch population over the past eighty years and fit local climate, agricultural practices and dietary preferences. Diets that are tailored to people's preferences and expectations are likely to have a higher success of adoption given the cultural context.

Another component of social sustainability is social equality and equity. This concept has been largely underexplored in diet-related LCA research. One of the recent attempts to assess social sustainability of various dietary patterns has indicated that 'Vegan' dietary pattern had poorer social sustainability than pescetarian and omnivorous diets (Norris, Norris & Tichenor, 2014). Although all three food dietary patterns were modeled according to the Dietary Guidelines for Americans, the rationale for selecting components of each basket was ambiguous and potentially biased, since the methodology did not rely on the current dietary preferences within each of the dietary patterns. Thus, there is a vast scope for further diet-related social research.

Along with the social perspective towards a sustainable diet, it is important to account for the economic implications. Barilla Center for Food and Nutrition suggested that the cost associated with the healthier and more environmentally diet heavily depends on economic literacy and informed food choices of the public (BCFN, 2014). A few LCA studies have incorporated an economic perspective to the development of a sustainable diet and showed that, despite an increased consumer cost during the transition to a healthy diet, it is offset by the reduction in environmental costs (Saxe & Jensen, 2014). Another interesting finding suggests that with a higher extent of social acceptability of a healthy and low impact diet come higher costs (Wilson et al., 2013).

Overall, development of sustainable dietary guidelines signifies an overarching approach and suggests incorporation of a wider range of environmental impacts, economic ramifications and social implications of food choices, thus presenting scientific community with ample opportunities for further research.

6. Food waste and sustainable diet

The present study illustrated significant reduction potential for diet-related environmental impact through reducing food waste, which is an alternative to and seemingly more feasible than changing consumption behavior.

Potential GWP reduction is largely present at a household level. Thus, consumer behavior is a decisive factor in reducing the GWP associated with the food waste. A slight to moderate reduction of avoidable food waste can significantly reduce the use of resources and energy, and all the impacts associated with cultivation, processing, transportation, preparation and post-consumer processing. Minimizing waste associated with the high-impact foods such as meat, dairy, eggs, resource-intensive products such as imported or greenhouse-grown fruit and vegetables as well as foods with a large share of avoidable waste (Table 2 Appendix B) should be of top priority, given a higher reduction potential.

According to Gooch, Felfel and Marenik (2010), one of the key steps in reducing the food waste in households is changing purchasing behavior and educating the general public about forms of storage, types of packaging and strategies to prevent foods from spoilage. Businesses, particularly, food retailers can play a leading role in reducing food waste by educating public and providing guidance on household food handling. They are also encouraged to offer loyalty programs and promotions that can prevent household food waste such as offering coupons for future purchases instead of selling 'two for the price of one' (Gooch, Felfel & Marenick, 2010). Meanwhile, food producers and processors can potentially contribute by improving the quality of food packaging, contributing to longer shelf life.

Food waste along the supply chain accounts for around 2% of the Canadian GDP (Gooch, Felfel & Marenick, 2010). Thus, food waste reduction can also have an economic advantage.

All in all, food waste reduction presents a great opportunity for preventing avoidable GHG emissions and reducing costs associated with food consumption without directly modifying eating habits.

To understand the magnitude of the food waste implications, country- and food group-specific data are required for further analysis. A collaborative effort could be undertaken by Statistics Canada and Environment Canada to collect food waste related data as a part of the next large-scale population survey.

7. Limitations & Results

The interpretation of the results and further recommendations has to be done with caution due to the existing limitations of the study. The data quality, being one of the biggest limitations, and method-related limitations play a crucial role in the reliability and generalizability of results.

7.1 Identifying dietary patterns

The resulting dietary patterns were determined based on 2004 data. Updated data on the food intake from the CCHS (2015) is likely to change the composition of the resulting dietary patterns in Ontario and reflect the current dietary patterns more accurately. These changes may potentially affect the environmental performance of food baskets, given that the results are conditional upon the inclusion of particular foods in the food baskets and their consumed amounts.

Given the limitations of 24-hour recall method (Chapter 2, Section 3.1), the dietary patterns reflected only a sample of Ontario population on a single day. Given that food consumption varies on a daily basis, the data might have not accurately reflected the foods consumed on a regular basis throughout the year and could have affected the representation of the dietary patterns. Although the applied method was based on the single-day food consumption, the analysis still provided an insight into environmental impact of realistic one-day diets in Ontario.

7.2 Nutritional assessment

The findings of nutritional assessment may be affected by a number of limitations including the composition of the food baskets, consumed amounts and recommended intakes, choice of reference for assessment, and population distribution within each basket.

The baseline consumption within each dietary pattern was based on the average amounts of consumed foods. Due to limitations of this method, and differences between individual diets, the generalizations about nutritional adequacy and environmental implications of a particular dietary pattern should also be made with caution. Given that the purpose of the study was not focused on the individual diets, the baseline average consumption provided sufficient basis for assessing the adequacy of the dietary pattern as a whole and did not affect the results.

Commonly consumed foods were chosen to represent typical food consumption within each diet. They serve as an approximation of the actual consumption and might underestimate the variety of different foods consumed within each category, which have varying calorie and protein intakes. This could have been a limitation to reflecting the true environmental impact associated with all the consumed foods.

The nutritional assessment of the diet was conducted based on the annual food basket which was extrapolated from the actual daily consumption within each dietary pattern. Given the limitations of this method (Chapter II, Section 3.1), this could have affected the composition of the annual food baskets and consequently could potentially change the nutritional assessment and the life cycle analysis results.

Nutritional assessment was also performed with respect to the gender and age-weighted Health Canada recommendations for an average person in Ontario. Potential variations in the gender and age distribution within each of the dietary patterns might have affected the nutritional assessment results and subsequent adjustments to optimize nutritional value of the food baskets. Gender-based analysis may potentially produce different recommendations. This in turn is likely to affect the composition of the nutritionally adjusted food baskets and their environmental performance.

Assessing how well consumers within each dietary pattern meet the healthy eating guidelines and recommended amount of servings for particular food groups was preferred to assessing the intake of nutrients from the foods due to the limited scope of the study. Analyzing the nutrient content of the food baskets would substantially contribute to making the nutritional analysis of the current dietary patterns stronger and can be recommended for further research.

Along with analyzing the key macronutrients such as protein, the study would benefit from additional assessment of macro-minerals and vitamins, and micronutrients. A more comprehensive nutritional assessment would need to incorporate the use of supplements to accurately assess the nutritional adequacy of the current dietary preferences in Ontario. Inclusion of the supplements in the analysis is also likely to affect the results of the LCA given the additional environmental impact associated with the production and the consumption of the dietary supplements.

The choice of the nutritional standard, however, could have affected the modeling of nutritionally balanced food baskets and potentially affected the results of the subsequent LCA

and proposed recommendations. Although Canada's Food Guide is a national dietary guideline, the dietary patterns can also be assessed against other standards such as the World Health Organization guide or Food Pyramid in future research.

7.3 Quantifying the environmental impact

The life cycle modeling was largely dependent on the results of the cluster analysis and the composition of each of the food baskets. Thus the quality of the dietary data used to identify the food consumption patterns in Ontario was decisive in the LCA.

Another important limitation stems from the quality of the LCI data. Although some international LCI databases are available, they often lack transparency, consistency and completeness and need regular updates (Peano et al., 2014). Moreover they may not be representative of the local agricultural and production practices and related emissions.

According to Emhart et al. (2014), the lack of consistent and reliable life cycle inventories is the key obstacle to using the LCA results in the food-related policy making. Given the lack of Canadian data on food and agricultural production and a heavy dependence on the international databases for the diet-related research, there is a strong demand for the development of a detailed country-specific LCI database.

Canada is one of the largest producers and exporters of agricultural products. Thus the database of the life cycle inputs and emissions related to the Canadian specific production practices will facilitate not only the diet-related research in Canada but also internationally and support the efforts to ensure the sustainability of the global food system.

As a part of concerted effort to improve the quality of agricultural and food-related research, a number of regionally specific databases are under development, including the Chilean Food & Agriculture LCI Database (Emhart et al., 2014), AGRIBALYSE® database containing life cycle inventory of over 100 products (Colomb et al., 2014) and the World Food LCI database, which is scheduled for release later this year (Peano et al., 2014). Thus, there is a need for government support for the creation of the Canadian agricultural and food database.

8. Contribution

The present study identified the lack of data on the food preferences of Ontario population and filled the information gap by identifying the distribution of a large population sample among the most common dietary patterns.

This LCA of the dietary patterns in Ontario initiates diet-related LCA research in Canada. Canada is one of the leading producers and exporters of food and agricultural products, thus quantifying the environmental implications of the Canadian key economic sector will facilitate the adoption of strategies to minimize it environmental footprint and meet the current GHG reduction targets.

The present study also contributes to the on-going dialogue and research on the environmental footprint of food in Canada. The current research in Canada primarily focuses on the food production rather than consumption (Kissinger, 2012; Xuereb, 2005). This study brings forth a new perspective by looking at the implications of a diet as a whole and the actual food consumption patterns typical for the Ontario population. As opposed to research on the footprint of single food items, the diet-related research provides a realistic perspective on the consumed amounts and the magnitude of the impact.

The study also contributes to the interdisciplinary research supporting the nexus of nutritional and environmental sciences and policy-making. Food consumption has multidimensional implications ranging from nutrition and health, environment and food security to the agricultural traditions and innovations. Thus, research and related policy-making also need to be multidisciplinary to secure nutritional and food security and environmental sustainability.

The present study facilitates a deeper understanding of the problem in diet-related research. Apart from filling the knowledge gap, the study identified another gap in the current research, namely the lack of the nutritional and environmental assessment of the use of supplements within various dietary patterns. The food consumption patterns have a long-lasting and profound effect on the health and the environment. Including the supplements in the analysis will provide more insights into the sustainability of the current food consumption.

This study also assessed the sustainability of three new dietary patterns that have not been previously considered in diet related LCAs ('No Red Meat', 'No Pork', 'No Beef'). These dietary patterns are variations of an omnivorous diet that is widely assessed in other countries. However, creating socially acceptable recommendations for the impact reduction greatly depends on the preferences within each of the subgroups. Thus, the increase of lower-impact meat alternative such as pork would not be suitable within the 'No Pork' or 'No Red Meat' food patterns pertinent to Ontario. Such differentiation helps better understand the overall impacts, individual hotspots and potential improvements of the meat-based dietary patterns. It also

increases the social acceptance and facilitates adoption of the proposed diets, since formulating a unique nutritionally balanced and environmentally favorable diet for each of the existing dietary patterns seems more compelling than a universal diet for the entire population and is likely to facilitate an easy and fairly quick transition to a healthier lifestyle with lower environmental impact.

9. Conclusion

In conclusion, our food choices have a profound impact on climate change. This necessitates a great level of personal responsibility in what we consume and presents substantial scope for improvement. Climate change mitigation, food security and health can be promoted not only by the government and businesses, but also by consumers. Given the universal economic law that 'demand drives supply', daily consumer choices have a strong potential to influence the food sector and consequently alleviate its impact on the environment.

Further research opportunities

This exploratory study identifies limitations, presents opportunities for improvements and serves as a primer for further research.

One of the next steps in diet-related environmental research in Canada would include updating the dietary data obtained in the CCHS 2015, which will provide an accurate assessment of the current dietary patterns in Ontario and their environmental performance. Comparative study can also be carried out to identify the environmental repercussions of the shifts in dietary preferences occurring for the past decade.

The area of primary focus should be the data quality. Filling the gaps in the data collection, expanding the food portfolios and available life cycle inventories, and using the country-specific database in the LCA would substantially improve the accuracy of the assessment.

The present research would also benefit from expanding the focus of the study and including a wide range of impact categories such as water use, eutrophication, biodiversity loss, human and ecosystem toxicity, among others.

Moreover, it would be interesting to explore the nutritional and environmental implications of including dietary supplements in the analysis. This would require using an updated CCHS data on the use of supplements among the Ontario population and collecting the data on the

material inputs and emissions associated with the production and consumption of dietary supplements.

Finally, future studies could apply the framework of the present study to identify the common dietary patterns across Canada or local dietary choices in other Canadian provinces, assess their nutritional adequacy and environmental performance, and propose diet-related changes to minimize the environmental impact and improve the nutritional value of the current diets.

Recommendations

Based on the study results and limitations, recommendations are provided to policy makers, businesses and consumers.

Policy makers

* Given the significance of the food sector for the economy and the magnitude of the associated environmental impact, the government should set policy to address environmental performance of the food sector, particularly beef industry;

* There is also the need to promote diet-related research and development of sustainable dietary guidelines through collaboration of nutritionists and environment professionals;

* Given the increasing importance of diet-related research and existing data gaps, the government should support the creation of a country-specific agricultural and food database.

Business

* In collaboration with the governmental agencies, food industry should incorporate environmental labeling to help promote sustainable food choices in Canada;

* Introduction of environmentally friendly menu options in restaurants and school lunches will reinforce the provision of sustainable food options;

* Given the reduction potential associated with the household food waste, retailers should provide consumers with proper guidance about food storage and handling to prevent household food waste.

Consumers

The knowledge obtained in this study provides consumers with a general direction for improving environmental performance attributed to their food consumption.

* Consumers are suggested to make informed food choices and follow dietary guidelines securing a healthy and sustainable diet;

* To make the first steps in reducing their carbon footprint, consumers are prompted to minimize consumption of high-impact foods such as beef, dairy products, eggs, coffee, greenhouse-grown produce and perishable import foods;

* Alternatively or complementary to reducing consumption of high-impact foods, consumers are advised to minimize food waste in households.

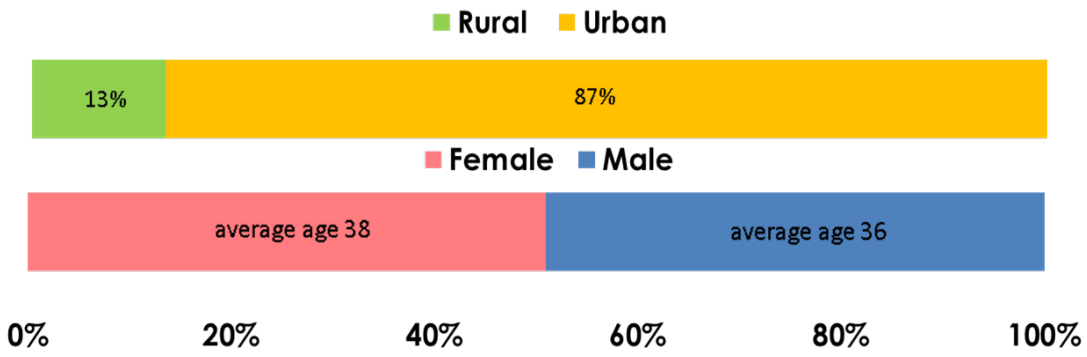
Appendix A

Supplemental information for the Cluster Analysis

Table 1. Coding system for the food groups

Coding system for the Food groups			
00	'UNKNOWN'	**11.1**	'VEGETABLE JUICES'
01	'DAIRY AND EGGS' and dairy-based SOUP/SAUCE/GRAV.	**12**	'NUTS AND SEEDS'
02	'SPICES AND HERBS'	**13**	'BEEF', 'SAUSAGE/L.MEAT beef
03	'BABYFOODS'	**14**	'BEVERAGES'
04	'PLANT-BASED FATS AND OILS'	**15**	'FIN/SHELL(FISH)', SOUP/SAUCE/GRAV. With fish / seafood
04.101	'ANIMAL FATS: PORK'	**16**	'LEGUMES'
04.17	'ANIMAL FATS: GAME MEAT'	**17**	'LAMB/VEAL/GAME', 'SAUSAGE/L.MEAT game meat
04.5	'ANIMAL FATS: POULTRY'	**18**	'BAKED PRODUCTS'
04.13	'ANIMAL FATS: BEEF'	**18.1**	'BAKED PRODUCTS containing egg & dairy'
04.15	'ANIMAL FATS: FISH'	**19**	'SWEETS'
05	'POULTRY', 'SOUP/SAUCE/GRAV.' With poultry, 'SAUSAGE/L.MEAT poultry	**19.1**	'SWEETS containing dairy'
07	'SAUSAGE/L.MEAT' mixed / unspecified	**19.2**	'SWEETS containing gelatin'
08	'BREAKFAST CEREAL'	**20**	'GRAINS'
08.1	'BREAKFAST CEREAL' containing dairy	**20.1**	'PASTA'
09	'FRUITS	**22**	'UNSPECIFIED MIXED DISHES'
09.1	'FR.JUICES'	**25**	'SNACKS'
10	'PORK', 'SAUSAGE/L.MEAT pork	**25.1**	'SNACKS containing dairy'
11	'VEGETABLES', SOUP/SAUCE/GRAV. Without meat with vegetables	**40**	'WATER'

Figure 1. Statistics of the Ontario sample population.



Supplement 1. Description of the data collection process for the Canadian Community Health Survey

The participants were initially contacted by mail with an introductory letter and a pamphlet describing the survey. Then a trained Statistics Canada interviewer collected basic demographic information by phone or personal visit. The interviewer was required to attempt to contact potential participants at least six times. If participation was refused, they were contacted by a senior interviewer who requested and highlighted the importance of their participation. These strategies helped ensure high response rates (Health Canada, 2004b).

Subsequent interviews were held at participants' homes between January 2004 and January 2005 on all days of the week. As a result, the mean intake data obtained from the population sample accounted for seasonal variability and were representative of all days throughout the sample year.

The survey was designed on the basis of the computer-assisted 24-hour recall method from the United States Department of Agriculture (USDA, n.d.) Automated Multiple-Pass Method (AMPM) (National Cancer Institute, n.d.). This method is believed to yield high quality data with a minimum bias and is widely considered a valid and often preferred methodology for monitoring dietary intakes, studying diet-disease correlations and determining eating patterns (Moshfegh et al., 2008; National Cancer Institute; Nicklas, Carol, & Fulgoni, 2014; Subar et al., 2012).

The participants were asked to list all the foods consumed on the previous day. The computer program assisted the respondents in documenting their dietary recalls to ensure accuracy of the food portion estimates and completeness of the recall. After compiling a list of main meals, the participants were asked to enter the foods consumed between the meals as well as before or after the first or last meal, respectively (National Cancer Institute, n.d.). Respondents also had to provide the details about the consumed foods such as the consumed

amount, source, form, preparation methods and use of condiments (National Cancer Institute, n.d.). A Food Model Booklet assisted the participants in estimating the amount of food that was consumed accurately (Health Canada, 2004b). Respondents were also prompted to specify the eating occasion and time, and where the food or beverage was prepared and consumed (National Cancer Institute, n.d.).

To ensure completeness of the food list, respondents were offered a list of commonly forgotten foods and drinks such as coffee, tea, snacks and fruit among others. After the final review of all reported foods and drinks a pop-up window reminded respondents to add any potentially forgotten items again.

Unless it was a second dietary recall, respondents were not aware that the interview included a 24-hour recall of their food consumption. Given that not all respondents in the sample agreed to participate in the second recall, the sample was covered partially and results of the second recall were not included in the analysis.

To minimize the bias and potential underreporting associated with the focus of the survey, the non-response adjustment was applied to survey weights. The response rate for CCHS was relatively high (76.5%), thus the results were considered representative of the population.

Appendix B

Supplemental information for the Life Cycle Assessment

Table 1. Commonly consumed foods in seven food baskets

Commonly consumed foods						
Vegan	Vegetarian	Pescetarian	No Red Meat	No Beef	No Pork	Omnivorous
Dairy & Eggs						
-			milk, partly skimmed			
-			egg, raw			
-			butter, regular			
-	cheese, hard	cheese, hard	-	-	-	cheese, hard
Herbs & Spices						
			salt, table			
Fats & Oils						
			margarine, tub, unspecified vegetable oils			
			vegetable oil, canola			
-	-	-	-	-	-	olive oil
Poultry						
-	-	-	chicken, roasted	chicken, roasted	chicken, roasted	chicken, roasted
Cereal						
oats, quick, cooked	-	oats, quick, cooked	oats, quick, cooked	oats, quick, cooked	oats, quick, cooked	oats, quick, cooked
ready to eat cereal	ready to eat cereal	-	ready to eat cereal	ready to eat cereal	ready to eat cereal	ready to eat cereal
Fruit						
			apples, raw			
			bananas, raw			
			oranges, raw			
			grapes, raw			
papayas, raw	-	-	-	-	-	-
strawberries, raw	-	-	strawberries, raw	-	strawberries, raw	-
pineapple, raw	-	-	-	-	-	-
melons, raw	-	-	-	-	-	-
pears, raw	-	pears, raw	-	-	-	-
Fruit juice						
			apple juice + vitamin c			
			orange juice			
grape juice	grape juice					
Pork						
-	-	-	-	pork, roasted	pork, roasted	pork, roasted
Vegetables						
			lettuce, iceberg, raw			
			onions, raw			
			tomatoes, raw			
-	carrots, raw	carrots, raw	carrots, raw	carrots, raw	carrots, raw	-
olives, ripe, canned	-	-	-	-	-	-
cauliflower, boiled	-	-	-	-	-	-
peppers, sweet, raw	-	-	-	-	-	-
carrots, boiled	-	-	-	-	-	-
zucchini, boiled	-	-	-	-	-	-
broccoli, boiled	-	-	-	-	-	-
cabbage, boiled	-	-	-	-	-	-
potatoes, baked	-	-	-	-	-	-
-	tomatoes, canned, whole	-	-	-	-	-
tomato puree, canned	tomato puree, canned	-	-	-	-	-

Commonly consumed foods						
Vegan	Vegetarian	Pescetarian	No Red Meat	No Beef	No Pork	Omnivorous
Vegetable Juice						
tomato juice						
Nuts & Seeds						
almond butter		peanut butter, smooth, fat, sugar and salt added		walnuts, dried		
-	peanuts, roasted	peanuts, roasted	peanuts, roasted	peanuts, roasted	peanuts, roasted	-
-	cashew nuts, roasted	cashew nuts, roasted	-	-	-	-
-	almonds, dried	almonds, roasted	almonds, dried	almonds, dried	-	almonds, dried
Beef						
-	-	-	-	-	beef, ground, pan fried	beef, ground, pan fried
Beverages						
beer (5% alcohol by volume)	-	-	coffee, brewed tea, brewed -	-	-	-
carbonated drinks, cola	carbonated drinks, cola	carbonated drinks, lemon-lime soda	carbonated drinks, cola	carbonated drinks, cola	carbonated drinks, cola	carbonated drinks, cola
-	coffee, instant	-	coffee, instant	coffee, instant	coffee, instant	-
Fish						
-	-			salmon, canned		
-	-			tuna, canned		
Legumes						
tofu, regular, fried (calcium sulfate)	soy patty	beans, snap, canned	beans, snap, canned	-	beans, snap, raw	-
soybeans, dry, boiled	lentils, boiled	-	-	-	-	-
peas, split, boiled	-	peas, grean, boiled	peas, green boiled beans, snap, boiled	peas, green, boiled	peas, green, boiled	peas, green, boiled
Baked goods						
bread, toasted	bread, toasted	-	bread, white bread, toasted	bread, toasted	-	-
Sweets						
fruit butters, apple	jams and preserves	jams and preserves	jams and preserves sugars, granulated	jams and preserves	-	-
Grains						
rice, white, long, cooked						
Flour						
wheat flour, white						
Pasta						
spaghetti, enriched, cooked						
Snacks						
granola bars			potato chips			

Table 2. Food waste during processing, at retail and household levels for different food categories. Estimates are based on the UK food waste data used by Trolle et al. (2015). Asterisk marks estimates for the Region of Waterloo, calculated by Urrutia Shroeder (2014).*

Food group	Avoidable food waste (%)				
	Household			Retail	Processing
Milk & dairy products	3			2	2
Cheese	3			2	2
Egg	18	5.5	12.5*	2	2
Fats	3			2	2
Poultry	13	0.5	12.5*	2	2
Fruit	26			6	2
Juice	18			2	2
Meat	13	0.5	12.5*	2	2
Vegetables	45	32.5	12.5*	6	2
Potatoes	19	6.5	12.5*	2	2
Salad	45			6	2
Beverages	3			2	2
Canned/packaged foods*	5.8*			-	-
Bread	31			2	2
Rice, pasta (and assuming grains)	31	18.5	12.5*	6	2
Sugar & candy (and assuming snacks)	18			2	2

Supplement 1. Life Cycle Inventory

1- Dairy products

* The greenhouse gas emissions are calculated by Vergé et al. (2007) for Ontario dairy production, based on 2006 data (Vergé, Dyer, Desjardins, & Worth, 2007). System boundaries of the study are from cradle to processing plant, including transportation from farm to processing. The transport from processing plant (Kraft Canada) to retail (500km) is added (Transport, lorry 20-28t, fleet average/CH U)

http://www.cdc-ccl.gc.ca/CDC/index-eng.php?id=3802

Milk

* The packaging is assumed to be a glass bottle with a plastic lid and is modeled based on the LCA study on the packaging materials for milk and dairy products (Amienyo, Gujba, Stichnothe, & Azapagic, 2013; Ghenai, 2012).

* Waste is calculated based on the data on food waste for milk and dairy products in the UK (Table 2)

Butter

* The packaging is assumed to be a polypropylene tub (500 grams) and is modeled based on the data on weight of the packaging material for a margarine tub (PYR, n.d.).

* Waste is calculated based on the data on food waste for fats in the UK (Table 2)

Cheese

* The packaging is assumed to be a high-density polyethylene (HDPE) packaging (500 grams) and is modeled based on the data on weight of the packaging material for meat and cheese (PYR, n.d.)

* Waste is calculated based on the data on food waste for milk and dairy products in the UK (Table 2)

Egg

* The greenhouse gas emissions from agricultural processes are calculated by Vergé et al. (2009) for egg and poultry production, based on the national average production in 2006.

The productivity in 2006 was around 186 eggs / hen / year (Vergé, Dyer, Desjardins, & Worth, 2009b). Poultry feed is comprised primarily of wheat and corn, soybean, canola and barley.

System boundaries of the study include field operations, farm transport, heating fuels, electricity, machinery supply, and chemical supply, but do not include long-range transport (Vergé et al., 2009b).

* Processing was not included in the farm operations. The transport from the farm (Burnbrae Farms, Lyn, ON) to the processing plant (Supreme Egg Products Inc. in Etobicoke, ON – 346km) and to retail (500km) is added (Transport, lorry 20-28t, fleet average/CH U)

http://www.burnbraefarms.com/consumer/about_us/index.htm
http://supremeegg.com/en/home/

* One of the most common preparation methods of eggs is boiling (Egg, hard boiled)

Cooking yield factor that reflects the loss in weight of a cooked egg is 0.9 (Bognár, 2002). Cooking is assumed to be done for 1 kg of a product. Time that is required for boiling 3 liters of water is 7.99 minutes on a small stove (1200W) and 15 minutes for boiling eggs.

http://www.seriouseats.com/2009/10/the-food-lab-science-of-how-to-cook-perfect-boiled-eggs.html

* Waste is calculated based on the data on food waste for milk and dairy products in the UK (Table 2)

2 – Herbs & spices

* Salt is sourced from Goderich, Ontario.

Process is adopted from Ecoinvent 'Sodium chloride, powder, at plant / RER U
Included processes: this module includes the solution mining process of sodium chloride (thermo compressing technology), its cleaning form impurities, and the drying step.

* Processing is done by Sifto Canada on-site in Goderich, ON.

* Distribution and packaging is done by Compass Materials in Mississauga. The process includes transportation from the mine to distribution center (187km) and to retail (500km)

http://www.frasers.com/supplier/compass-minerals-16692964106?type=B
http://www.siftocanada.com/en/about-us/how-we-produce/mechanical-evaporation/

* Salt is packaged in a cardboard box (350 grams) that is modeled based on data for a cereal box (PYR, n.d.).

4 - Fats & Oils

Canola oil

* Canola oil was modeled based on the production of canola in Alberta (Pelletier, Arsenault, & Tyedmers, 2008). System boundaries of the study include cradle to farm gate operations, including farm machinery (i.e. fuel for field operations and crop drying), the production of fertilizers/soil amendments, seed, and pesticides, field-level nitrous oxide and ammonia emissions from fertilizers and crop residues. Inputs and emissions associated with the production and maintenance of farm machinery and infrastructure, transportation of inputs, soil carbon sequestration or methane production were not included.

* Processing was assumed to be done at Cargill in Clavet, SK. Extraction and refining was modeled as an average between sunflower and rapeseed oil processing in Europe (Katarina Nilsson et al., 2010). Rapeseed and sunflower oil production were taken as proxies due to similar oil content in seed (40% compared to 43% in canola) (Canola Council, 2009). The allocation between oil and meal was done on a mass basis.

Transportation of canola from farm (Grande Prairie, AB) to canola oil producer was added (998km). Oil is transported to a distribution centre at Saporito Foods in Markham, ON (2966km) and to retail (500km).

http://albertacanola.com/
http://www.cargill.ca/en/products-services/canola-processing/index.jsp
http://www.saporitofoods.com/location.php

* Packaging for canola oil was modeled as a 1-liter HDPE (PYR, n.d.).

Margarine

One of the most common fats and oils is margarine. Given that oils used in the production of the margarine were not specified, it was assumed that the margarine is primarily based on canola oil. The product was modeled as non-hydrogenated unsalted margarine with 75% fat content.

* Transportation was included from the oil processing plant (Cargill) to the Unilever processing plant in Rexdale, ON (2939km), then to distribution centre at Saporito Foods in Markham, ON (28km) and to retail (500km).

http://www.magazine-awards.com/index.php?tmpl=util_pdf_force_inline&file=http://www.magazine-awards.com/multimedia/krwawards_assets/assets/files/awards/5/3077.pdf
http://www.saporitofoods.com/location.php

* The packaging for margarine was modeled based on the 500-gram polypropylene tub (Canola Council, 2009; PYR, n.d.).

Olive oil

82.5% of olive oil is imported from Italy (Industry Canada, 2014).

The LCI is based on the olive oil production in Sicily, Italy (Salomone & Ioppolo, 2012). The system boundaries of the study include cradle to farm gate processes, including agricultural cultivation, olive oil production and olive oil mill waste treatment.

Cultivation, processing, packaging and waste treatment occurs in Sicily. Conventional technology for cultivation is practiced by 47% farmers, three-phase pressing system is used by 67% of mills and composting of waste - by 90% of farmers (Salomone & Ioppolo, 2012).

* The Sicilian province with the largest area of olive cultivations is Messina (Salomone & Ioppolo, 2012). Transportation is added from the Messina port to Toronto port by sea (2718km). Additional transportation includes transportation to a distribution centre in Concord (Maximum Food Sales – 42km) and transportation to retail (500km)

* Packaging is modeled as 1-liter glass bottle with an aluminum twist top (PYR, n.d.).

5 - Poultry

Broiler chicken

* The greenhouse gas emissions are calculated by Vergé et al. (2007) for poultry production in East provinces of Canada, based on 2006 data [1]. System boundaries of the study are from cradle to farm gate, including field operations, farm transport, heating fuels, electricity, machinery supply, and chemical supply, but not including food processing and long-range transport.
* The transport is added from farm (Clark Poultry Farms Ltd in Binbrook, ON) to a processing plant (Hagersville, ON – 24km), to a distribution centre (West End Meat Packers in Toronto, ON – 96km) and to retail (500km) (Transport, lorry 20-28t, fleet average/CH U).

* Live weight to retail weight calculations are based on conversion factors from USDA (USDA, 1992). According to USDA estimates, 72.62% of the live animal converts to edible meat. Thus, environmental impacts associated with the production of 1 kg of white meat is linked to 1.38 kg Live Weight equivalent of a broiler chicken.

* The most common preparation method for chicken is roasting.

Cooking yield factor is 0.75 (Bognár, 2002). Oven is preheated at 200"C for 20 min and the roasting time is 1 hour 20 minutes.

* Packaging is assumed to be a high-density polyethylene (HDPE) packaging (500 grams) and is modeled based on the data on weight of the packaging material for meat and cheese [4].

7 - Mixed meat

The mixed meat products are represented by a sausage. The recipe is based on the LCA study of a meat sausage in Sweden (Abelmann, 2005).

* Processing includes grinding, pre-mixing, extruding, conveyor operations, peeling and packaging. The sausage protein content is 8.5-8.6%. Processing is done by the Great Canadian Meat company in Whitby, ON.

* The transportation includes transportation of the main ingredients (pork, beef – 123-125km) and transportation of the packaged product to retail (500km).

* Packaging is assumed to be a high-density polyethylene (HDPE) packaging (500 grams) and is modeled based on the data on weight of the packaging material for meat and cheese (PYR, n.d.).

* Cooking method: pan-frying 'brat' style.

Cooking yield 0.95 (Bognár, 2002). Time: 4-5 min each side (total of 20min)

8 - Cereal

Oats

Ontario produces around 60 ton of oats per year with a yield of around 2,474.43 kg/ha (OMAFRA, 2013a). The life cycle inventory was available from the oat production in Denmark (LCA Food Database DK) where yield is around 4,340 kg/ha.

* Milling process to convert the oats to oat flakes was adopted from the Danish Food database. All processes consider Ontario electricity mix (Ontario Energy Board, 2013). Milling is assumed to occur in close proximity to the farm and transportation is considered negligible.

* Transportation from the farm to Quaker processing facilities in Peterborough, ON (331km) and retail (500km) was added.

http://www.londonag.com/services/barley.html
https://cu.pepsico.com/caen/quaker

* Cooking process was modeled according to existing LCA of oatmeal porridge (McDevitt & Milà i Canals, 2011). The cooking yield factor for oat flakes is 4.10, thus 0.04kg of oat flakes yield 0.164 kg of ready-to-eat oatmeal (Bognár, 2002). Energy was calculated for cooking 1 kg of oatmeal, based on the ratio of 3:1 (water/oats). Cooking time is 6 minute on a small burner. Time needed for boiling water is 1 min.

Breakfast cereals

The breakfast cereals are represented by Cheerios.

Production and transportation of the key ingredients is included in the analysis (sugar and oats). Processing data was missing.

* Cereal is packaged in a cardboard box (350 grams) that is modeled based on data for a cereal box (PYR, n.d.).

9 - Fruit

Apple

Modeling was based on the life cycle inventory from the LCA study of the apple production in Nova Scotia, that has yield of 23.66 tn / growing season (Keyes, Tyedmers, & Beazley, 2015).

* The LCI was adapted to include Ontario fertilizer mix and electricity mix. The system boundaries of the adopted LCI include processes from cradle to farm gate, excluding production or maintenance of capital goods. It includes land preparation, nutrient management, fuel use by farm machinery and pest and disease management.

* Processing is assumed to be done on-site, at the farm. Data on processing is missing.

* Transportation to distribution center at the Canadian Fruit and Produce company in Mississauga, ON (159km) and retail (500km) is added.

* Apples are sold in loose. PE bags are used to pack a pound of produce. Assumptions for fruit and vegetable packaging are based on the EPA report on the environmental impacts of packaging of fresh tomatoes (EPA, 2010).

* Apples are consumed raw. According to USDA, 9% of fruit is non-edible (USDA, 2014). Non-edible parts are considered as unavoidable food waste, avoidable waste is added according to UK estimates (Trolle, Mogensen, Jørgensen, & Thorsen, 2014)

Banana

The life cycle inventory for bananas is based on the Swiss LCA study on fruit and vegetables, including Colombian bananas (Stoessel, Juraske, Pfister, & Hellweg, 2012). Ontario's key import sources for banana over the past 5 years are Costa Rica (31.6%),Colombia (28.1%) and Guatemala (18.8%)(IndustryCanada, 2014). Thus, LCI on Colombian bananas is considered suitable.

* The system boundaries of adopted LCI include processes from cradle to point of sale, including irrigation, nutrient and pest management, transport from farm to port. The destination from the Colombian port is changed to Toronto port (1998km) for the transoceanic transportation. Transportation to the distribution centre in Canadian Fruit and Produce company in Mississauga, ON (31km) and retail (500km) is added.

* Bananas are sold in loose. PE bags are used to pack a pound of produce

* Bananas are consumed raw. 36% of banana is non-edible (USDA, 2014). Non-edible parts are considered as unavoidable food waste, the avoidable food waste during processing, retail operations and at the household is calculated according to the UK estimates (Trolle et al., 2014).

Grapes

Ontario produces 82,906 tn per 6,606 ha, yield = 1.3kg/m^2 (Statistics Canada). Local production is assumed to be allocated partly for consumption and mainly for the wine production. Demand for grapes is primarily met through import. Ontario's key import sources for grapes over the past 5 years are California, US (51.9%) and Chile (29.5%).

* LCI of Spanish grapes is used as a proxy for Californian and Chilean grapes (Stoessel et al., 2012). The system boundaries: cradle to point of sale. Data is added for transportation from California to the distribution center at the Canadian Fruit and Produce company in Mississauga, ON (4104km) and retail (500km).

* Processing is assumed to be carried out before the transportation to Ontario. Data on processing is missing.

* Grapes are sold unpacked, loose. PE bags are used to pack a pound of produce

* Grapes are consumed raw. 4% is non-edible (stems) (USDA, 2014). Non-edible parts are considered as unavoidable food waste, the avoidable food waste during processing, retail operations and at the household is calculated according to the UK estimates (Trolle et al., 2014).

Orange

Oranges are represented by mandarin oranges in the LCA. Ontario's key import sources for oranges over the past 5 years are California, US (48.8%) and Morocco (20.66%). Given the limited data availability, the LCA of Italian oranges is used as a proxy for Californian oranges (Stoessel et al., 2012).

* System boundaries: cradle to point of sale. Data is added on the transportation from California to the distribution center at the Canadian Fruit and Produce company in Mississauga, ON (4147km) and to retail (500km).

* Processing is assumed to be carried out before the transportation to Ontario. Data on processing is missing.

* Oranges are sold loose. PE bags are used to pack a pound of produce

* Oranges are consumed raw. 25% of an orange is non-edible (USDA, 2014). Non-edible parts are considered as unavoidable food waste, the avoidable food waste during processing, retail operations and at the household is calculated according to the UK estimates (Trolle et al., 2014).

Melon

Ontario produces a small amount of melons - 9,062 tn per 321 ha, yield = 2.8 kg / m^2 (OMAFRA, 2013b) . Given that it is not commonly consumed fruit (CCHS), the consumers' demand is assumed to be met through the local production.

* The LCI was available from the Swiss LCA study on fruit and vegetables, including melon from France (Stoessel et al., 2012). It was adapted to include Ontario electricity mix. System boundaries: cradle to point of sale.
Transportation is added from farm to the distribution center at the Canadian Fruit and Produce company in Mississauga, ON (92km) and to retail (500km).

* Processing is assumed to be carried out before the transportation to Ontario. Data on processing is missing.

* Melon is either sold as halves - each around 1kg packed in PE plastic film (equals 2 plastic bags), or whole - packed in larger PE bag (approximately 2 plastic bags).

* Melon is consumed raw. 49% of melon is non-edible (USDA, 2014). Non-edible parts are considered as unavoidable food waste, the avoidable food waste during processing, retail operations and at the household is calculated according to the UK estimates (Trolle et al., 2014).

Papaya

Ontario's key import sources for papaya over the past 5 years are Costa Rica (16.8%) and Mexico (44%). Given the limited data availability, the Brazilian production is used as a proxy for Costa Rican production (Stoessel et al., 2012).

* System boundaries: cradle to point of sale. The data was added for air freight from the airport of Costa Rica to Toronto (3810km), to the distribution center at the Canadian Fruit and Produce company in Mississauga, ON (26km) and to retail (500km).

* Processing is assumed to be carried out before the transportation to Ontario. Data on processing is missing.

* Papaya is either sold as halves - each around 1kg packed in PE plastic film (equals 2 plastic bags), or whole - packed in larger PE bag (approximately 2 plastic bags).

* Papaya is consumed raw. 38% of papaya is non-edible (USDA, 2014). Non-edible parts are considered as unavoidable food waste, the avoidable food waste during processing, retail operations and at the household is calculated according to the UK estimates (Trolle et al., 2014).

Pear

Ontario production of pears (2013) - 4,331 tn per 366 ha, yield = 1.2 kg / m^2 (OMAFRA, 2013b). Ontario's demand for pears is assumed to be met through the local supply.

* The LCI was available from the Swiss LCA study on fruit and vegetables, including pear production in Switzerland (Stoessel et al., 2012). The LCI was adapted to include Ontario electricity mix. System boundaries: cradle to point of sale. Transportation was added from farm to the distribution center at the Canadian Fruit and Produce company in Mississauga, ON (92km) and to retail (500km).

* Processing is assumed to be carried out on-site at the farm. Data on processing is missing.

* Pears are sold loose. PE bags are used to pack a pound of produce

* Pears are consumed raw. 10% is non-edible (USDA, 2014). Non-edible parts are considered as unavoidable food waste, the avoidable food waste during processing, retail operations and at the household is calculated according to the UK estimates (Trolle et al., 2014).

Pineapple

Ontario's key import sources for banana over the past 5 years are Costa Rica (94.1%) and Honduras (2.5%).

* Life cycle inventory was available for the pineapple production in Costa Rica (Stoessel et al., 2012). System boundaries: cradle to point of sale. Destination for the transoceanic transportations was changed to Toronto port (6408km), data was added for the transportation to the distribution center at the Canadian Fruit and Produce company in Mississauga, ON (31km) and to retail (500km).

* Processing is assumed to be carried out before the transportation to Ontario. Data on processing is missing.

* Pineapple is either sold as halves - each around 1kg packed in PE plastic film (equals 2 plastic bags), or whole - packed in larger PE bag (approximately equals 2 plastic bags).

* Pineapple is consumed raw. 49% of pineapple is non-edible (USDA, 2014). Non-edible parts are considered as unavoidable food waste, the avoidable food waste during processing, retail operations and at the household is calculated according to the UK estimates (Trolle et al., 2014).

Strawberry

Ontario is second largest producer of strawberry in Canada (32%) (Elmhirst, 2005). Ontario's local strawberry production is around 4,652 tn per 701 ha, thus the yield = 6,636 kg/ha (Elmhirst, 2005).

* LCI of strawberry production was available from the Swiss LCA study on fruit and vegetables, including Swiss strawberry production (Stoessel et al., 2012). System boundaries: cradle to point of sale. Data is added for the transportation of product to the distribution center at the Canadian Fruit and Produce company in Mississauga, ON (85km) and to retail (500km).

* Processing is assumed to be carried out on-site at the farm. Data on processing is missing.

* Strawberries are sold loose. PE bags are used to pack a pound of produce

* Strawberries are consumed raw. 6% is non-edible (stems and caps) (USDA, 2014). Non-edible parts are considered as unavoidable food waste, the avoidable food waste during processing, retail operations and at the household is calculated according to the UK estimates (Trolle et al., 2014).

9.1 – Fruit & Vegetable Juice

Production of the ingredients is based on the corresponding fruit production. Processing is assumed to be similar regardless of the juice type. The processing data is based on the European study on beverage and food production (Geneviève Doublet, Jungbluth, Stucki, & Schori, 2013). It was also assumed that each juicing plant produced one type of juice and disposed of all by-products.

Apple juice

According to Bognar (2002) the yield factor for apple juice is 0.70(Bognár, 2002). Thus, 1 kg apples yields 0.7kg of apple juice (centrifuge technology).

The LCI includes transportation from a farm to processing plant at Cott Beverages Canada (143km) and retail (500km).

Apple juice packaging is modeled as a 1-liter plastic bottle (PYR, n.d.).

Grape juice

According to Bognar (2002) the yield factor for grape juice is 0.74 (Bognár, 2002). 1 kg grapes yields 0.74kg of grape juice (centrifuge technology).

The LCI includes transportation from a farm to processing plant at Cott Beverages Canada (28km) and retail (500km).

Grape juice packaging is modeled as a 1-liter plastic bottle (PYR, n.d.).

Orange

According to Bognar (2002) the yield factor for orange juice is 0.48(Bognár, 2002). Thus, 1 kg oranges yields 0.48kg of orange juice (squeezing technology).

The LCI includes transportation from the distribution center at the Canadian Fruit and Produce company in Mississauga, ON to the processing plant at Cott Beverages Canada (28km) and retail (500km).

Orange juice packaging is modeled as a 1-liter plastic bottle (PYR, n.d.).

Tomato juice

According to Bognar (2002) the yield factor for tomato juice is 0.68 (Bognár, 2002). Thus, 1 kg of tomatoes yields 0.68kg of tomato juice (centrifuge method).
The LCI includes transportation from a farm to processing plant at Cott Beverages Canada (332km) and retail (500km).

Tomato juice packaging is modeled as 0.33-liter beverage can [4].

10 - Pork

* Greenhouse gas emissions associated with pork are calculated by Vergé and coworkers, based on 2001 data for pork production in the Eastern Canada (Ontario & Quebec)(Vergé, Dyer, Desjardins, & Worth, 2009a). Feed is corn-based. Sample is representative of the typical swine production system for Eastern provinces. System boundaries: cradle to farm gate, including the production of feed ingredients, use of energy and materials on farm and the storage and land application of manure.

* Processing is assumed to be carried out on-site at the farm. Processing data is missing.

* Data are added for transportation of the processed meat to the distribution center at the West End Meat Packers in Toronto, ON (69km) and retail (500km).

* Estimates per 1 kg of raw meat were calculated based on the conversion factors from 1 kg of Carcass Weight (USDA, 1992). 1 kg of Carcass Weight yields 72.9% boneless and skinless meat.

* The most common preparation method for pork is roasting. According to Bognar (2002), the yield factor for roasted pork (fillet) is 0.72 (Bognár, 2002). Cooking at 200'C for 1 hour.

* Packaging is assumed to be a high-density polyethylene (HDPE) packaging (500 grams) and is modeled based on the data on weight of the packaging material for meat and cheese [4].

* The avoidable food waste during processing, retail operations and at the household is calculated according to the estimates from UK and Region of Waterloo (Trolle et al., 2014; Urrutia Schroeder, 2014).

11 - Vegetables

Broccoli

Ontario's production of broccoli (2013) is around 8,259.8 kg/ ha = 0.8 kg/m^2 (OMAFRA, 2013c). It was assumed that all the broccoli are produced within the growing season and stored during the rest of the year. Given the limited data availability for local crop production, an LCI for the field-grown broccoli in Switzerland was used (Stoessel et al., 2012).

* System boundaries: cradle to point of sale. LCI was adapted to account for Ontario electricity mix. Transportation distances were calculated from farm to the distribution centre at the Canadian Fruit and Produce company in Mississauga, ON (38km) and retail (500km).

* Processing is assumed to be carried out on-site at the farm. Processing data is missing.

* Broccoli are sold loose. PE bags are used to pack a pound of produce

* Broccoli is consumed boiled. Cooking yield factor = 1.04 (Bognár, 2002). 4.6 minutes is required for boiling the water on a small stove (1200W) and 5 minutes are needed for cooking. 39% of broccoli is non-edible (leaves and tough trimmings) (USDA, 2014). Non-edible parts are considered as unavoidable food waste, the avoidable food waste during processing, retail operations and at the household is calculated according to the estimates from UK and Region of Waterloo (Trolle et al., 2014; Urrutia Schroeder, 2014).

Cabbage

Ontario's production of cabbage (2013) is around 39,075 kg/ha = 3.9 kg/m^2 (OMAFRA, 2013c). It was assumed that all the cabbage is produced within the growing season and stored during the rest of the year. Given the limited data availability for local crop production, an LCI for the field-grown cabbage in Switzerland was used (Stoessel et al., 2012).

* System boundaries: cradle to point of sale. LCI was adapted to account for Ontario electricity mix. Transportation distances were calculated from farm to the distribution centre at the Canadian Fruit and Produce company in Mississauga, ON (85km) and retail (500km).

* Processing is assumed to be carried out on-site at the farm. Processing data is missing.

* Cabbage is sold as a whole and packed in a larger PE bag (approximately 2 plastic bags) (PYR, n.d.)

* Cabbage is consumed boiled. Cooking yield factor = 1.15 (Bognár, 2002). 4.6 minutes is required for boiling the water on a small stove (1200W) and 18 minutes are needed for cooking. 20% of broccoli is non-edible (leaves and tough trimmings) (USDA, 2014). Non-edible parts are considered as unavoidable food waste, the avoidable food waste during processing, retail operations and at the household is calculated according to the estimates from UK and Region of Waterloo (Trolle et al., 2014; Urrutia Schroeder, 2014).

Carrot

Ontario's production of carrot (2013) is around 33,228.5 kg/ha = 3.3kg/m^2 (OMAFRA, 2013c). It was assumed that all the carrot is produced within the growing season and stored during the rest of the year. Given the limited data availability for local crop production, an LCI for the field-grown carrot in Switzerland was used (Stoessel et al., 2012).

* System boundaries: cradle to point of sale. LCI was adapted to account for Ontario electricity mix. Transportation distances were calculated from farm to the distribution centre at the Canadian Fruit and Produce company in Mississauga, ON (68km) and retail (500km).

* Processing is assumed to be carried out on-site at the farm. Processing data is missing.

* Carrot is sold loose. PE bags are used to pack a pound of produce (PYR, n.d.). Assumed to be sold without the crown (similar to baby raw carrots, refuse rate = 0%)

* Carrot is consumed raw or boiled. Cooking yield factor = 0.94 (Bognár, 2002). 4.6 minutes is required for boiling the water on a small stove (1200W) and 8 minutes are needed for cooking. The avoidable food waste during processing, retail operations and at the household is calculated according to the estimates from UK and Region of Waterloo (Trolle et al., 2014; Urrutia Schroeder, 2014).

Cauliflower

Ontario's production of cauliflower (2013) is around 20,629.6 kg/ ha = 2.06 kg/m^2 (OMAFRA, 2013c). It was assumed that all the cauliflower is produced within the growing season and stored during the rest of the year. Given the limited data availability for local crop production, an LCI for the field-grown cabbage in Switzerland was used (Stoessel et al., 2012).

* System boundaries: cradle to point of sale. LCI was adapted to account for Ontario electricity mix. Transportation distances were calculated from farm to the distribution centre at the Canadian Fruit and Produce company in Mississauga, ON (38km) and retail (500km).

* Processing is assumed to be carried out on-site at the farm. Processing data is missing.

* Cauliflower is sold as a whole and packed in a larger PE bag (approximately 2 plastic bags) (PYR, n.d.)

* Cauliflower is consumed boiled. Cooking yield factor = 1 (Bognár, 2002). 4.6 minutes is required for boiling the water on a small stove (1200W) and 5 minutes are needed for cooking. 61% of cauliflower is non-edible (leaf stalks, cores, trimmings) (USDA, 2014). Non-edible parts are considered as unavoidable food waste, the avoidable food waste during processing, retail operations and at the household is calculated according to the estimates from UK and Region of Waterloo (Trolle et al., 2014; Urrutia Schroeder, 2014).

Cucumber

Ontario's production of cucumber (2013) is around 1,008,599 kg/ha = 100.9 kg /m^2 (OMAFRA, 2013c). It was assumed that all the carrot is produced in greenhouses throughout the year. About 80% of Ontario's greenhouse vegetable area is in or near Leamington, Ontario (Dyer et al., 2011). Given the limited data availability for local crop production, an LCI for the greenhouse-grown cucumber in Switzerland was used (Stoessel et al., 2012).

* System boundaries: cradle to point of sale. LCI was adapted to account for Ontario electricity mix and greenhouse practices. Ontario's greenhouses operate 8.5 months a year. Source of heating energy - 84% natural gas, 13% heating oil, 2% liquefied petroleum gas (Dyer, Desjardins, Karimi-Zindashty, & McConkey, 2011). Transportation distances were calculated from farm to the distribution centre at the Canadian Fruit and Produce company in Mississauga, ON (317km) and retail (500km).

* Processing is assumed to be carried out on-site at the farm. Processing data is missing.

* Cucumber is sold loose. PE bags are used to pack a pound of produce (PYR, n.d.).

* Cucumber is consumed raw. 3% of cucumber is non-edible (ends) (USDA, 2014). Non-edible parts are considered as unavoidable food waste. The avoidable food waste during processing, retail operations and at the household is calculated according to the estimates from UK (Trolle et al., 2014).

Lettuce

Ontario's production of lettuce (2013) is around 20,545 kg/ha = 2 kg/m^2 (OMAFRA, 2013c). It was assumed that all the carrot is produced in greenhouses throughout the year. About 80% of Ontario's greenhouse vegetable area is in or near Leamington, Ontario (Dyer et al., 2011). Given the limited data availability for local crop production, an LCI for the greenhouse-grown cucumber in Switzerland was used (Stoessel et al., 2012).

* System boundaries: cradle to point of sale. LCI was adapted to account for Ontario electricity mix and greenhouse practices. Ontario's greenhouses operate 8.5 months a year. Source of heating energy - 84% natural gas, 13% heating oil, 2% liquefied petroleum gas (Dyer et al., 2011). Transportation distances were calculated from farm to the distribution centre at the Canadian Fruit and Produce company in Mississauga, ON (317km) and retail (500km).

* Processing is assumed to be carried out on-site at the farm. Processing data is missing.

* Lettuce heads are sold individually. PE bags are used to pack a pound of produce (PYR, n.d.).

* Lettuce is consumed raw. 5% of lettuce is non-edible (core) (USDA, 2014). Non-edible parts are considered as unavoidable food waste. The avoidable food waste during processing, retail operations and at the household is calculated according to the estimates from UK (Trolle et al., 2014).

Olives

Ontario's key import sources for olives over the past 5 years are Greece (39%) and Spain (41.5%) (IndustryCanada, 2014). Olive production in Sicily, Italy was used as a proxy to Greek and Spanish olives (Salomone & Ioppolo, 2012).

* System boundaries: cradle to farm gate. Conventional technology for cultivation practiced by 47% farmers is used as a reference. Data are added for the transportation from Messina port to Toronto port (2718mk), from port to the distribution center at the Unico Inc. in Concord, ON (39km) and retail (500km).

* Olives are consumed canned. Processing is assumed to be carried out on farm. Processing information for olives is missing. Packaging is modeled as an aluminum 0.33 food can with lid (PYR, n.d.).

* Percentage of food wastage for canned foods is missing. It was assumed that no food waste occurs at retail due to processed nature and long shelf life of canned olives. Food waste at the household level is calculated according to the estimates for packaged foods (Urrutia Schroeder, 2014).

Onion

Ontario's production of onion (2013) is around 39,848.8 kg / ha = 4 kg/m^2 (OMAFRA, 2013c). It was assumed that all the onion is produced within the growing season and stored during the rest of the year. Given the limited data availability for local crop production, an LCI for the field-grown onion in Switzerland was used (Stoessel et al., 2012).

* System boundaries: cradle to point of sale. LCI was adapted to account for Ontario electricity mix. Transportation distances were calculated from farm to the distribution centre at the Canadian Fruit and Produce company in Mississauga, ON (87km) and retail (500km).

* Processing is assumed to be carried out on-site at the farm. Processing data is missing.

* Onion is sold loose. PE bags are used to pack a pound of produce (PYR, n.d.).

* Onion is consumed raw. 10% of onion is non-edible (stem ends, peel and defects) (USDA, 2014). Non-edible parts are considered as unavoidable food waste, the avoidable food waste during processing, retail operations and at the household is calculated according to the estimates from UK(Trolle et al., 2014).

Pepper

Ontario's production of pepper (2013) is around 339,684 kg/ha = 34 kg/m^2 (OMAFRA, 2013c). It was assumed that all the peppers are produced in greenhouses throughout the year. About 80% of Ontario's greenhouse vegetable area is in or near Leamington, Ontario (Dyer et al., 2011). Given the limited data availability for local crop production, an LCI for the greenhouse-grown pepper in Switzerland was used (Stoessel et al., 2012).

* System boundaries: cradle to point of sale. LCI was adapted to account for Ontario electricity mix and greenhouse practices. Ontario's greenhouses operate 8.5 months a year. Source of heating energy - 84% natural gas, 13% heating oil, 2% liquefied petroleum gas (Dyer et al., 2011).

Transportation distances were calculated from farm to the distribution centre at the Canadian Fruit and Produce company in Mississauga, ON (317km) and retail (500km).

* Processing is assumed to be carried out on-site at the farm. Processing data is missing.

* Pepper is sold loose. PE bags are used to pack a pound of produce (PYR, n.d.).

* Pepper is consumed raw. 18% of pepper is non-edible (stem ends, seeds and core) (USDA, 2014). Non-edible parts are considered as unavoidable food waste. The avoidable food waste during processing, retail operations and at the household is calculated according to the estimates from UK (Trolle et al., 2014).

Potato

Ontario's production of potato (2013) is around 24.10 tn/ha , or 2.41 kg/m^2 (OMAFRA, 2013c). It was assumed that all the cauliflower is produced within the growing season and stored during the rest of the year. Given the limited data availability for local crop production, an LCI for an average field-grown potato from USLCI database was used as a proxy to Ontario potato production.

* System boundaries: cradle to farm gate, including soil cultivation, sowing, weed control, fertilization, pest and pathogen management, irrigation and harvest. Inputs of fertilizers, pesticides and seed as well as their transports to the farm are included. Conventional production technology typical for the country is used. Data were added for the transportation from farm to distribution center at the Canadian Fruit and Produce company in Mississauga, ON (124km) and retail (500km).

* Processing is assumed to be carried out on-site at the farm. Processing data is missing.

* Pepper is sold loose. PE bags are used to pack a pound of produce (PYR, n.d.).

* The most common preparation method for the potato is baking. Cooking yield factor is 0.81 (with peel) (Bognár, 2002). Baking in the oven lasts for 90 min. Potato is basked with skin, so no unavoidable waste occurs. The avoidable food waste during processing, retail operations and at the household is calculated according to the estimates from UK (Trolle et al., 2014).

Tomato

Modeling was based on the life cycle inventory from the LCA study of the greenhouse tomato production in Ontario (Dias, Ayer, et al., 2015).

* The system boundaries of the adopted LCI include processes from cradle to farm gate, including the greenhouse structure and operations, nutrient and pest management, irrigation.

* Processing is assumed to be done on-site, at the farm. Data on processing is missing.

* Transportation from farm to the distribution center at the Canadian Fruit and Produce company in Mississauga, ON (317km) and retail (500km) is added.

* Tomatoes are sold loose. PE bags are used to pack a pound of produce (PYR, n.d.).

* Tomatoes are consumed raw. According to USDA, 9% of fruit is non-edible (stem ends and core) (USDA, 2014). Non-edible parts are considered as unavoidable food waste, avoidable waste is added according to UK estimates (Trolle et al., 2014)

* Tomatoes are also consumed as puree / sauce. The processing is modeled based on the LCA study on the packaged tomato puree (Manfredi & Vignali, 2014). Thus, 1.39 kg of raw tomatoes yields 0.7kg of tomato puree.

Packaging is modeled as a glass canning jar with a tin lid (Manfredi & Vignali, 2014).

Data are added for the transportation of tomatoes from farm to the canning facility (Unico Inc. in Concord, ON – 344km) and to retail (500km).

Percentage of food wastage for canned foods is missing. It is assumed that no food waste occurs at retail due to the processed nature and long shelf life of canned tomato puree. Food waste at the household level is calculated according to the estimates for packaged foods (Urrutia Schroeder, 2014).

* Tomatoes are also consumed whole / canned. Processing data is missing.

Packaging is modeled based on Hunt's whole canned tomato specifications (1 serving = 121 gram of canned tomatoes (3.5 servings per can). Thus, 1kg of canned tomatoes requires 1.8 food cans.

Data are added for the transportation of tomatoes from farm to the canning facility (Unico Inc. in Concord, ON – 344km) and to retail (500km).

Percentage of food wastage for canned foods is missing. It is assumed that no food waste occurs at retail due to the processed nature and long shelf life of canned tomato puree. Food waste at the household level is calculated according to the estimates for packaged foods (Urrutia Schroeder, 2014).

Zucchini

Ontario's production of zucchini (2013) is around 9,656.6 kg/ha = 0.97 kg /m^2 (OMAFRA, 2013c). It was assumed that all the onion is produced within the growing season and stored during the rest of the year. Given the limited data availability for local crop production, an LCI for the field-grown zucchini in Switzerland was used (Stoessel et al., 2012).

* System boundaries: cradle to point of sale. LCI was adapted to account for Ontario electricity mix. Transportation distances were calculated from farm to the distribution centre at the Canadian Fruit and Produce company in Mississauga, ON (85km) and retail (500km).

* Processing is assumed to be carried out on-site at the farm. Processing data is missing.

* Zucchini is sold loose. PE bags are used to pack a pound of produce (PYR, n.d.).

* Zucchini is consumed boiled. Cooking yield factor - 0.73 (Bognár, 2002). Time required for boiling water is 4.6 minutes and for cooking – 10 minutes. 13% of zucchini is non-edible (ends) (USDA, 2014). Non-edible parts are considered as unavoidable food waste, the avoidable food waste during processing, retail operations and at the household is calculated according to the estimates from UK (Trolle et al., 2014).

12 - Nuts & Seeds

Almond

Ontario's key import sources for almond over the past 5 years is California (97%) (IndustryCanada, 2014) Modeling was based on the life cycle inventory from the LCA study of the almond production in California, US (Dias, Ayer, et al., 2015).

* The system boundaries of the adopted LCI include processes from cradle to processing plant gate. The final product of processing is a shelled almond. The unit of analysis is one hectare of orchard assessed over a time horizon equal to the productive lifespan of the orchard plus one year for orchard clearing and fallow – total of 26 years with an annual yield of 4091 kg / ha. Greenhouse gas emissions were calculated per 1 kg of almond kernels.

* Data are added for the transportation from farm to the processing and distribution center at the Planters Peanuts / Johnvince Foods Wholesale in Downsview, ON (4245km) and retail (500km).

* Packaging is modeled as a 500-gram nut bag, based on available specifications (http://www.alibaba.com/product-detail/Plastic-bag-for-organic-cashews-bag_1759413180.html)

* Almonds are consumed dried. The almonds are dried before arriving to processing facility (http://www.epa.gov/ttnchie1/ap42/ch09/final/c9s10-2a.pdf)

* Almonds are also consumed roasted. Almond roasting is modeled based on data for peanut processing (CARS, n.d.). Loss values are assumed similar. Almonds are roasted in a 500-pound drum roaster at 118'C for 1.25 hours. Wattage for a nut roaster is assumed to be 36 kW (http://www.alibaba.com/product-detail/high-quality-Industrial-Nut-roaster-Nut_1818348287.html)

Almond butter

Almond butter production is based on the almond production and import from California. Packaging and processing are modeled identically to peanut butter (CARS, n.d.). No addition of sugar, salt or oil. The LCI includes the transportation of ingredients from the distribution center

to production plant at the Kraft Canada LTD in Niagara-on-the-Lake (132km) and to retail (500km).

Cashew

Ontario imports cashews largely from Vietnam (63%), Brazil (18.7%) and India (6.8%). Given the limited data availability, the cashew production in Brazil was used in the analysis (de Figueirêdo et al., 2014).

* Dwarf cashew production in a low input farm model (10 farmers and 2 managers from largest production area - 57% of cashew production). System boundary: cradle to farm gate, including production of inputs (diesel, fertilizers and pesticides), transport of inputs to the cashew farm, and cultivation of dwarf cashew trees. Mass-based allocation between cashew nut, apple, gum and wood is preferred to economic allocation due to volatility of prices. Allocation for cashew nut is 15% (compared to economic allocation of 44%). GWP is calculated per 1kg of unshelled nuts.

* Processing is modeled based on peanut processing (CARS, n.d.). Loss values are assumed similar. Processing description is based on UNCTAD guidelines and African Cashew Alliance. http://www.unctad.info/upload/Infocomm/Docs/cashew/itdg.pdf
http://www.africancashewalliance.com/sites/default/files/documents/2011CashewBroch.pdf

* Cashews are consumed roasted. Cashew are cleaned and sieved by hand (no machinery used). Soaking is done by placing nuts in a 40-50 gallon drum, filling it with water and draining water 3 times (reaching 9% moisture content). Weight gain due to soaking is assumed to be cancelled out by moisture loss during the roasting process.
Drum roasting is modeled based on almond roasting: 500-pound drum roaster at 118'C for 1.25 hours (http://www.epa.gov/ttnchie1/ap42/ch09/final/c9s10-2a.pdf). Wattage for a nut roaster is assumed to be 36 kW (http://www.alibaba.com/product-detail/high-quality-Industrial-Nut-roaster-Nut_1818348287.html)
In Brazil, nuts are shelled by a semi-mechanized method (foot-operated machine). Around 10% of nuts are removed due to small size. Up to 20% of weight of nuts is cashew nut shell and liquid (http://www.africancashewalliance.com/sites/default/files/documents/2011CashewBroch.pdf).
These values constitute unavoidable food waste. No data for avoidable food waste for nuts is available.
Shelled roasted nuts are machine-dried at 70'C for 6 hours until the moisture content is 3% for storage (UNCTAD). The moisture content is restored before packaging back to 5%. Drying occurs in a machine with capacity up to 5 ton (UNCTAD). Wattage of a dryer (400kg) is 60kW (http://www.alibaba.com/product-detail/2013-Hot-Sale-Perfect-Drying-Industrial_1247006153.html)

* Packaging is modeled as a 500-gram nut bag, based on available specifications (http://www.alibaba.com/product-detail/Plastic-bag-for-organic-cashews-bag_1759413180.html)

* Data are added for the transportation of nuts from farm to the port in Brazil (50km), transoceanic freight to port of Toronto (7445km), to the processing and packaging plant at the Planters Peanuts / Johnvince Foods Wholesale in Downsview, ON (32km) and to retail (500km).

Peanut

Ontario primarily imports peanuts from Georgia, US (57.8%), China (14,3%) and Texas, US (10.3%) (IndustryCanada, 2014).

* Conventional non-irrigated peanut production in Georgia, US was used for the current LCI (CARS, n.d.). 80% of US farmers use conventional tillage, and 65% use no irrigation (CARS, n.d.). System boundaries: cradle to processing plant gate. Due to a lack of unit process data for inoculants, this input was excluded from the analysis. Seed requirements were also excluded. Different pesticides were listed for the varying production practices. thus a generic EcoInvent pesticide was used instead.

* Processing is carried out in close proximity to the farm and transportation is considered negligible. Processing is modeled based average US peanut processing and includes shelling, blanching and roasting. Losses along the supply chain are considered.

* Packaging is modeled as a 500-gram nut bag, based on available specifications (http://www.alibaba.com/product-detail/Plastic-bag-for-organic-cashews-bag_1759413180.html)

* Data were added for the transportation from the peanut processing facility in US to the distribution centre at the Planters Peanuts / Johnvince Foods Wholesale in Downsview, ON (1871km) and to retail (500km)

Peanut butter

Peanut butter is modeled based on the peanut production in Georgia and national average processing process (CARS, n.d.). Canola oil, sugar and salt are added. LCI includes the transportation of ingredients to the production plant at the Kraft Canada LTD in Niagara-on-the-Lake and transportation of the packaged product to retail (500km). Packaging is modeled as a 16 oz plastic container (14.4oz content ~ 408 gram of peanut paste) (CARS, n.d.) .

Walnut

Ontario imports walnuts largely from California (97.5%). Modeling was based on the life cycle inventory from the LCA study of the walnut production in California, US (Dias, Ayer, et al., 2015).

* The system boundaries of the adopted LCI include processes from cradle to processing plant gate. The final product of processing is a shelled walnut. The unit of analysis is one hectare of orchard assessed over a time horizon equal to the productive lifespan of the orchard plus one

year for orchard clearing and fallow – total of 36 years with an annual yield of 9314 kg / ha. Greenhouse gas emissions were calculated per 1 kg of almond kernels.

* Data are added for the transportation from farm to the processing and distribution center at the Planters Peanuts / Johnvince Foods Wholesale in Downsview, ON (4171km) and retail (500km).

* Packaging is modeled as a 500-gram nut bag, based on available specifications (http://www.alibaba.com/product-detail/Plastic-bag-for-organic-cashews-bag_1759413180.html)

* Walnuts are consumed dried. Drying is modeled according to Rumsey, T., & Thompson, J. (1984) (Rumsey & Thompson, 1984). Average drying time for Sacramento is 74.3-84.3 hours. Weight change while drying is 58%.

13 - Beef

Currently the beef processing industry in Ontario is sourcing a significant amount of beef from Alberta (60% to 80%)(HarryCummings & AssociatesInc., 2005). The greenhouse gas emissions associated with beef production were calculated by Dias et al. (2015) for cow-calf operations in Manitoba and feedlot operations in Alberta, Canada (Dias, Kariyapperuma, et al., 2015).

* Production system is common to the Western provinces and rest of Canada. System boundaries: cradle to farm gate. Feed: barley grain & silage, mixed legume-grass hay. Carbon sequestration is not accounted for.

* Estimates for 1 kg of raw meat were calculated based on the GWP associated with 1 kg of Live Weight. Conversion factors were used based on the USDA data (USDA, n.d.). 1 kg of Live Weight of steers/heifers yields 60% of Carcass weight, which in turn yields 73% of boneless trimmed retail cuts. Thus, 1kg LW yields 438 g of meat.

* Processing data is missing. Data were added for transportation from the farm to the processing facility at the Cargill Meat Solution in Guelph, ON (3256km) and to retail (500km)

* Packaging is assumed to be a high-density polyethylene (HDPE) packaging (500 grams) and is modeled based on the data on weight of the packaging material for meat and cheese [4].

* The most common preparation method for beef is pan-frying ground beef. Meat is assumed to be mechanically ground in household. Cooking yield factor = 69% (Bognár, 2002). Pan frying over a medium heat requires 5.3 minutes.

* The avoidable food waste during processing, retail operations and at the household is calculated according to the estimates from UK and Region of Waterloo (Trolle et al., 2014; Urrutia Schroeder, 2014).

14 - Beverages

Beer

Due to limited data availability, the beer is assumed to be imported. Ontario has been importing beer primarily from Netherlands (27.8%), US (20%) including Wisconsin, US (11.7%), Belgium (9.8%) and UK (8.7%) over the past 5 years (IndustryCanada, 2014). Greenhouse gas emissions were calculated for the UK microbrewery beer production with the traditional technology (Shefford Bitter beer) (Lalonde, Nicholson, & Schenck, 2013).

* System boundaries: cradle to delivery to outlets. Distance to outlets is assumed to be similar to the distance to port. Data were added for further transoceanic freight to port of Toronto (5637km), distribution centre at the Beer Store company in Mississauga, ON (30km) and to retail (500km).

* Packaging is modeled as a 0.33 aluminum can (Amienyo et al., 2013).

Carbonated drinks

Modeling was based on the LCA study of carbonated drinks (Amienyo et al., 2013). LCI for citric acid (3%), sodium benzoate (0.02%), coloring, flavoring and additives such as caffeine (0.02%) is missing.
According to Statistics Canada data, the majority of Soft Drink and Ice Manufacturing takes place in Ontario (85 establishments). Thus, the beverages are assumed to be produced by Cott, one of the world's largest producers of beverages on behalf of retailers, brand owners and distributors

http://www.cott.com/our-company/who-we-are
http://www.agr.gc.ca/eng/industry-markets-and-trade/statistics-and-market-information/by-product-sector/processed-food-and-beverages/the-canadian-soft-drink-industry/?id=1172167862291

Packaging was modeled as a 0.5-liter plastic PET bottle (Amienyo et al., 2013).

Coffee

For the past five years Ontario imported coffee primarily from Colombia (31.7%), Brazil (22.7%) and Guatemala (17%) (IndustryCanada, 2014). Coffee production at farms in Brazil, Colombia and Vietnam was used in the current LCI (Humbert, Loerincik, Rossi, Margni, & Jolliet, 2009).

* LCI included cultivation and transportation from farm to port in Colombia (50km), transoceanic transportation to port of Toronto (3215km) and to Nestle Canada production plant (25km).

* Coffee is consumed brewed from grounds. Processing was modeled based on available LCA study on various coffee preparation methods (Humbert et al., 2009). Processing includes:

1. Green coffee handling & cleaning

2. Roasting
3. Grinding
4. Filling & packing
5. Conditioning

Ground roasted coffee is packaged in a 250-gram tin can (Humbert et al., 2009).

Coffee is brewed in a drip machine (stand-by power is not included). Standard ratio 10 grams of coffee to 0.180 liter of water is used. Wattage of coffee drip machine is 1500W. Time: 8 minutes.

http://www.starbucks.ca/coffee/learn/how-to-brew
http://www.wholesalesolar.com/solar-information/how-to-save-energy/power-table
http://www.cnet.com/news/drip-coffee-101-essential-lessons-learned-testing-home-coffeemakers/

* Coffee is also made from instant coffee. Processing of spray dried coffee is based on the LCA study on various coffee preparation methods (Humbert et al., 2009). Processing includes:

1. Green coffee handling & cleaning
2. Roasting
3. Aroma recovery
4. Extraction
5. Evaporation
6. Spray drying
7. Agglomeration
8. Filling & packing
9. Conditioning

Packaging is modeled as a 250-gram metal can (Humbert et al., 2009).

Brewing requires 2.8 minutes to heat 1 liter of water in a kettle. Kettle energy 2000 W. 1 liter of brewed instant coffee equals 10 cups that contain around 20 grams of spray dried coffee.

http://processheatingservices.com/water-heating-time-calculator/
http://www.daftlogic.com/information-appliance-power-consumption.htm

Tea

Ontario imports most of its tea from UK (44%), USA (17%), India (9.4%) and China (8.9%) (IndustryCanada, 2014). Given the limited data availability, the LCA of the tea from Darjeeling, Northern India was used (Geneviève Doublet & Jungbluth, 2010).

* System boundaries of the LCA included cultivation, harvesting and processing. Data are added for the transportation of tea from farm to the port in Mumbai (2408km), transoceanic freight to

Toronto (15751km), to the distribution centre at the Unilever Canada Inc. in Toronto, ON (9km) and to retail (500km).

* Tea is assumed to be consumed in a tea bag. One tea bag contains 1.75 grams of tea. Packaging-related emissions are calculated and include paper, string, cardboard, LDPE film, corrugated board and packaging process (Geneviève Doublet & Jungbluth, 2010). Tea to water ratio used for brewing is 1.75 gr to 250 ml (7 gr per 1 liter).

15 - Fish

Salmon

The LCI for salmon is created based on the existing LCA study on salmon production in British Columbia, Canada based on a conventional marine net-pen system (Ayer & Tyedmers, 2009).

* System boundaries: cradle to farm gate

* Estimates per 1 kg of edible fish are calculated based on GWP of 1 kg of harvest ready fish and USDA conversion factors (USDA, n.d.). Thus, 1 kg of Live Weight of (fresh or frozen) fish yields 45% of edible fish.

* The most commonly consumed form of salmon is canned salmon. Processing occurs in British Columbia. Given the data gaps, processing of tuna fish in Spain is taken as a proxy to the Canadian processing (A. Hospido, Vazquez, Cuevas, Feijoo, & Moreira, 2006). 200 g of salmon in sunflower oil (net weight; 150 g of drained weight) is canned per a steel can. Steel can is modeled based on the can production in Spain (A. Hospido et al., 2006)

* Data were added for the transportation of salmon to Toronto by air (4,593km), to the distribution centre at the Gold Seal in Toronto, ON (10km) and to retail (500km).

* Processing accounts for food waste during multiple stages of processing. No food waste is assumed to occur at retail due to processed nature and long shelf life of canned fish. Avoidable food waste at the household level is calculated according to estimates for packaged food in the Region of Waterloo (Urrutia Schroeder, 2014).

Tuna

The key supplier of tuna to Ontario market over the past 5 years was Thailand (80%) (IndustryCanada, 2014). The Thai tuna is primarily caught from the Indian and Western Pacific Oceans (Mungkung et al., 2012). Due to limited data availability, the LCI for tuna was based on the tuna production in Spain as an average catch in the Indian & Pacific Oceans (Almudena Hospido & Tyedmers, 2005).

* The tuna is represented by Skipjack and Yellowfin tuna which is abundant and widely distributed in tropical and subtropical marine waters; it constitutes around 70% of tuna catch

(Almudena Hospido & Tyedmers, 2005). Purse seining fishing technology (60-70% of catch) was referred to. System boundary: cradle to farm gate, excluding vessel construction and maintenance.

* The most commonly consumed form of tuna is canned tuna. Processing occurs in Thailand. Given the data gaps, processing of tuna fish in Spain is taken as a proxy to the Thai processing (A. Hospido et al., 2006). LCI for Hydrochloric acid (37%) and Mercury used in the laboratory is missing. 200 g of tuna in sunflower oil (net weight; 150 g of drained weight) is canned per a steel can. Steel can is modeled based on the can production in Spain (A. Hospido et al., 2006).

* Processing accounts for food waste during multiple stages of processing. No food waste is assumed to occur at retail due to processed nature and long shelf life of canned fish. Avoidable food waste at the household level is calculated according to estimates for packaged food in the Region of Waterloo (Urrutia Schroeder, 2014).

* Data were added for the transportation of tuna to Toronto by sea (19,498km), to the distribution centre at the Kaymax Trading Ltd in Toronto, ON (14km) and to retail (500km).

16 - Legumes

Green peas

Ontario's production of zucchini (2013) is around 3602 kg/ha = 0.36 kg /m^2 (OMAFRA, 2013c). It was assumed that all the peas are produced within the growing season and frozen for the rest of the year. Given the limited data availability for local crop production, an LCI for the field-grown peas in France was adopted from EcoInvent.

* System boundaries: cradle to farm, including processes of soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides and seed as well as their transports to the farm are considered. The direct emissions on the field are also included.

* Processing is modeled based on the LCA study of some vegetables (Mila i Canals et al., 2008). Data were added for the transportation from farm to the processing facility at the Green Giant, General Mills in Mississauga, Ontario (278km) and to retail (500km).

* Frozen peas are sold in a 4-pound bag (Schenck, 2007). PE bags are used to pack a pound of produce (PYR, n.d.).

* Green peas are consumed boiled. Cooking yield factor - 0.89 (Bognár, 2002). Time required for boiling water is 2.66 minutes and for cooking – 3 minutes.

* Food wastage during processing is 14.2% while processing from raw to frozen (leaves, faulty produce, etc) and 6.5% from packing frozen peas (Mila i Canals et al., 2008). No food waste was

assumed to occur at retail due to processed nature and long shelf life of frozen peas. The avoidable food waste at the household is calculated according to the estimates for packaged foods from the Region of Waterloo (Urrutia Schroeder, 2014).

Split peas

LCI of split peas is based on the LCI of green peas. Given that peas are dried naturally, there is no additional energy required for processing.

Split peas are consumed boiled (dried, unsoaked). Cooking yield factor - 3.55 (Bognár, 2002). Higher cooking yield factor (relative to fresh peas) accounts for the weight / moisture loss in dried peas. Boiling the water requires 2.66 min, cooking - 2 hours (http://allrecipes.com/howto/split-pea-soup/). Food waste estimates for legumes are missing. They are considered minimal due to a long shelf life of dried peas. The avoidable food waste of cooked peas is calculated based on the estimates from the Region of Waterloo (Urrutia Schroeder, 2014).

Soy beans

Greenhouse gas emissions associated with soy beans are calculated by Pelletier and coworkers (2008) for Ontario's soy production (Pelletier et al., 2008).

* System boundaries: cradle-to-farm gate, including farm machinery (i.e. fuel for field operations and crop drying), the production of fertilizers, seeds, pesticides, and field-level nitrous oxide and ammonia emissions from fertilizers and crop residues. Inputs and emissions associated with the production and maintenance of farm machinery and infrastructure as well as transportation of inputs, soil carbon sequestration or methane production was not considered.

* Processing is assumed to be carried out on-site at the farm, Processing data is missing. Data were added for the transportation of beans from farm to the distribution center at the Agris Co-operative Ltd. In Chatham, ON (113km) and to retail (500km).

* The most common preparation method for soy beans is boiling. Cooking yield factor is 2.79 (Bognár, 2002). 1 kg of beans is boiled in 3 liters of water for 2 hours (http://www.lesliebeck.com/foods/soybeans). Food waste estimates for legumes are missing. They are considered minimal due to a long shelf life of dried soy beans. The avoidable food waste of cooked peas is calculated based on the estimates from the Region of Waterloo (Urrutia Schroeder, 2014).

Soy sausage

Modeling was based on the LCI of soy beans and the recipe from the LCA study on legumes (Abelmann, 2005). The sausage protein content is 8.5-8.6%. Canola oil was substituted for rapeseed oil, potato starch for corn starch, rice for rice meal.

* Processing of soy beans for the extraction of textured soy protein is missing. The ratio of soy beans to the output of textured protein is used. Further processing of all the ingredients is based on the LCA study of legume consumption (Abelmann, 2005)

* Data were added to include transportation of all the ingredients from farm to the processing at the Ying Ying soy product company and to retail (500km).

* Packaging is assumed to be a high-density polyethylene (HDPE) packaging (500 grams) and is modeled based on the data on weight of the packaging material for meat and cheese [4].

* Cooking was assumed to be similar to a meat-based sausage - pan-fried 'brat' style. Cooking yield 0.95 (Bognár, 2002). Time: 4-5 min each side (total of 20min).

* No food waste was assumed to occur at retail due to processed nature and long shelf life of packaged sausage. Food waste of packaged foods at a household level was calculated based on the estimates from the Region of Waterloo (Urrutia Schroeder, 2014).

Snap beans

Ontario's production of snap beans (2013) is around 6555.9 kg/ha = 0.66 kg/m^2 (OMAFRA, 2013c). It was assumed that all the snap beans are produced within the growing season and frozen for the rest of the year. The beans in Ontario are available starting June, thus an early planting (March) was considered. Given the limited data availability for local crop production, an LCI for the field-grown snap beans in the UK was used(Mila i Canals et al., 2008).

* System boundary: cradle to farm gate, including soil management, fertilizer use, irrigation, pest and disease management, harvesting. Carbon sequestration was not considered. Data were added to include the transportation from farm to the processing and distribution centre at the Canadian Fruit and Produce company in Toronto, ON (77km) and retail (500km).

* Processing of raw snap beans is assumed to be carried out on-site at the farm. Processing data is missing. Cooling, freezing and packaging is modeled according to the UK processes (Mila i Canals et al., 2008).

* Packaging was based on data from Schenck (2007).

* Food wastage is accounted for during processing. 14.2% is wasted while processing from raw to frozen beans (leaves, faulty produce, etc), 6.5% - during packaging of frozen beans (Mila i Canals et al., 2008). No food waste is assumed to occur at retail due to processed nature and long shelf life of frozen beans. Avoidable food waste at the household level was calculated similarly to vegetables based on the estimates for the UK (Trolle et al., 2014).

* Raw snap beans are sold loose. PE bags are used to pack a pound of produce (PYR, n.d.). Frozen snap beans are packed in 4-pound bags (Schenck, 2007).

* Snap beans are consumed ***raw*** or ***boiled***. Boiled beans are cooked from frozen beans. Cooking yield factor - 0.93 (Bognár, 2002). Time required for boiling water is 8 minutes, for cooking - 5 min. (http://allrecipes.com/recipe/buttery-garlic-green-beans/)

*Beans are also consumed ***canned***.

Processing for canned snap beans is modeled based on the LCA study on canned beans (Schenck, 2007). Packaging is assumed to be a 425-gram can, where half of the content is water (Schenck, 2007). Thus, there are 212.5 grams of beans per can. Avoidable food waste at the household level was calculated based on the estimates for packaged foods from the Region of Waterloo (Urrutia Schroeder, 2014).

Tofu

Modeling was based on the LCI of soy production in Ontario (Pelletier et al., 2008).

* Processing is modeled based on the production practices at the Dayspring Tofu, British Columbia (Black, Lee, Petrusa, Thoreau, & Tseung, 2010). Data were added to include the transportation of soy from the farm to processing plant at the Ying Ying Soy Food in Mississauga, ON (165km) and retail (500km).

* Tofu is consumed fried. Time required for cooking is 11 minutes.
(http://www.lesliebeck.com/foods/soybeans)

* No food waste was assumed to occur at retail due to processed nature and long shelf life of packaged tofu. Avoidable food waste at the household level was calculated based on the estimates for packaged foods from the Region of Waterloo (Urrutia Schroeder, 2014).

18 - Baked goods

Bread

Modeling was based on the wheat production in the Western Prairies / Alberta (Pelletier et al., 2008).

* System boundaries: cradle-to-farm gate, including the fuel used by farm machinery for field operations and crop drying, production of fertilizers, seeds, pesticides, field-level nitrous oxide and ammonia emissions from fertilizers and crop residues. Inputs and emissions associated with the production and maintenance of farm machinery and infrastructure, transportation of inputs, soil carbon sequestration or methane production were not accounted for.

* Processing (milling) is based on the milling process in the LCA Food DK database. Data were added to include transportation from the farm to the milling facility at the P&H Mill in Cambridge (2578km), to production plant at the Stonemill Bakehouse in Toronto, ON (102km) and retail (500km).

* Packaging is modeled as 1 plastic bag per 800gr-loaf (Espinoza-Orias, Stichnothe, & Azapagic, 2011).

* For ***toasted bread***, the preparation was based on toasting one slice at a time.

Toaster wattage is 900W. Time: 216 seconds (0.06 hour) per 14 mm piece. Weight of a standard medium slice is 14 gr (Espinoza-Orias et al., 2011). Thus, per kg of bread, there are 71.4 slices.

http://www.dailymail.co.uk/sciencetech/article-2017338/The-perfect-piece-toast-Scientists-test-2-000-slices-216-seconds-optimum-time.html

* Avoidable food waste is calculated based on the estimates from the UK (Trolle et al., 2014).

19 – Sweets

Sugar

Ontario has been importing sugar primarily from Costa Rica (28%) and US (13.6%), largely from Florida. Due to limited data availability, the LCI was based on Brazilian production in EcoInvent database as a proxy to production in Costa Rica.

* System boundaries: cradle to sugar refinery, including transportation of sugarcane to the sugar refinery and processing of sugarcane to sugar, ethanol (95% w/w), bagasse (79% dry matter, excess), excess electricity and vinasse from ethanol production. Juice extraction is performed through milling technology. Energy supply is done by combustion of the bagasse resulting from the extraction stage.

* LCI referred to the production of 1 kg sugar, respectively 1 kg of ethanol (95% w/w dry basis, i.e. 1.05 kg hydrated ethanol 95% wet basis), 1 kg of excess bagasse (wet basis, 79% dry matter), 1 kWh of electricity and 1 kg of vinasse. Economic allocation was used.

* Data were on added to include transportation of sugar from port in Costa Rica to port of Toronto (6408km), to the distribution center at the MA Global Corp in Brampton, ON (47km) and retail (500km).

* Food waste during processing is accounted for in the LCI. No food waste was assumed to occur at retail due to processed nature and long shelf life of packaged sugar. Avoidable food waste at the household level was calculated based on the estimates for sweets in the UK (Trolle et al., 2014).

Strawberry jam

Modeling is based on the popular recipe (http://www.jamieoliver.com/recipes/fruit-recipes/incredible-homemade-strawberry-jam/#lsc61PdBtpIyH34c.97). The jam is assumed to be

prepared at home. Preparing 2 liters of strawberry jam required 1 kg of strawberries and 500 gr of sugar. Cooking time is 10 minutes.

* Packaging was modeled as a 700-gram canning glass jar with a tin lid (Manfredi & Vignali, 2014).

* No processing and retail food waste was considered. Food waste at a household level was calculated according to the estimates for sweets from the UK (Trolle et al., 2014).

Apple butter

Modeling is based on the popular recipe (http://www.food.com/recipe/crock-pot-apple-butter-93886?mode=metric&st=true&scaleto=4). The jam is assumed to be prepared at home. Preparing 2.26 kg of apple butter required 2.5 kg of apples and 0.81 kg of sugar. Cooking time is 12 hours.

* Packaging was modeled as a 700-gram canning glass jar with a tin lid (Manfredi & Vignali, 2014).

* No processing and retail food waste was considered. Food waste at a household level was calculated according to the estimates for sweets from the UK (Trolle et al., 2014).

20 - Grains

Wheat flour

Modeling was based on the wheat production in the Western Prairies / Alberta (Pelletier et al., 2008).

* System boundaries: cradle-to-farm gate, including the fuel used by farm machinery for field operations and crop drying, production of fertilizers, seeds, pesticides, field-level nitrous oxide and ammonia emissions from fertilizers and crop residues. Inputs and emissions associated with the production and maintenance of farm machinery and infrastructure, transportation of inputs, soil carbon sequestration or methane production were not accounted for.

* Processing (milling) is based on the milling process in the LCA Food DK database. Data were added to include transportation from the farm to the milling facility at the P&H Mill in Cambridge (2578km) and retail (500km).

* Packaging is modeled as a 1-kg paper packet (PYR, n.d.).

Rice

Ontario has been importing rice over the past 5 years primarily from Arkansas, US (29.5%), Thailand (19.4%), India (15.9%) and California, US (13.5%). The rice production in the US was used from the USLCI database.

* System boundary: cradle to farm gate, including soil cultivation, sowing, weed control, fertilization, pest and pathogen control, irrigation and harvest. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides and seed, their transports to the farm are considered. The direct emissions on the field are also included.

* Processing is modeled based on the diesel and electricity use at the processing mill in Thailand (Yossapol & Nadsataporn, 2008). Data were added to include transportation from farm to the distribution center at the T J Food Imports in Mississauga, ON (1725km) and retail (500km).

* Packaging was modeled based on the LCA study on rice packaging in Thailand (Wimvipar et al., 2014).

* Rice is consumed boiled. Cooking yield factor - 2.98 (Bognár, 2002). Time for boiling water is 1.8 minutes and cooking - 15 minutes (http://www.bbcgoodfood.com/technique/how-cook-rice).

* Food wastage at processing, retail and household level are calculated based on the estimates for the UK and Region of Waterloo (Trolle et al., 2014; Urrutia Schroeder, 2014).

20.1 - Pasta

Life cycle inventory for pasta production is based on a published study by Bavilacqua et al. (Bevilacqua, Braglia, Carmignani, & Zammori, 2007) while wheat production for pasta is based on the study by Pelletier and coworkers (Pelletier et al., 2008) on Canadian wheat.

* Wheat is transported from Saskatchewan to Ontario for processing (3,039 km). Semolina is processed at the P&H Milling Group in Cambridge, Ontario, one of the largest Canadian-owned milling company (P&H, n.d.). Milled semolina is transported to the pasta production facility at the Italpasta in Brampton, ON (76km). Packaged pasta is transported to retail (500km).

* Data on processing (milling and pasta production) and packaging are taken from Bavilacqua et al. (Bevilacqua et al., 2007). Packaging and secondary packaging is assumed to be cardboard (40g)

* Pasta is assumed to be produced in Brampton, Ontario (Italpasta). Distance from milling facilities is 88.6 km

* Pasta is consumed boiled. Cooking yield factor is 2.10 (Bognár, 2002). Water boiling requires 12.69 minutes, cooking pasta – 10 minutes.

* Food wastage at processing is accounted for. Avoidable food waste at retail and a household level are calculated based on the estimates for the UK and Region of Waterloo (Trolle et al., 2014; Urrutia Schroeder, 2014).

25 – Snacks

Granola bar

Modeling is based on the popular recipe of Nature Valley Oats 'n Honey classic granola bar (http://www.popsugar.com/food/Crunchy-Granola-Bars-Recipe-29452056). Data on the commercial production process is missing. Energy intake is calculated from the recipe (baking for 1 hour).

* Data were added to include transportation of ingredients from their processing and distribution facilities to the production plant at the General mills, Mississauga, ON and to retail (500km).

* Packaging is calculated based on the available dimensions and information on the packaging specifications.

Potato chips

Modeling was based on the potato production in Ontario.

* Processing of potato chips was based on the LCA studies on the snack food production and potato processing (Moudrý Jr et al., 2013; K. Nilsson, Sund, & Florén, 2011).

* Data were added to include the transportation of key ingredients (potato, canola oil, salt) from the distribution centers to the production plant at the Frito Lay in Cambridge, ON and to retail (500km).

* Avoidable food waste during processing, at retail and a household level was calculated based on the estimates for snacks in UK (Trolle et al., 2014).

Ontario electricity mix

Process was modeled based on the Electricity Supply Mix 2013, published by the Ontario Energy Board (OntarioEnergyBoard, 2013).

23.4% hydro (Electricity, hydropower, at reservoir power plant/FI U)
57.9% nuclear (Electricity, nuclear, at power plant/US U)
0.9% natural gas (Electricity, natural gas, at power plant/US U)
2% coal (Electricity, hard coal, at power plant/US U)
3.9% wind (Electricity, at wind power plant 2MW, offshore/OCE U)
1% biomass (Electricity, biomass, at power plant/US)
0.8% solar (Electricity, production mix photovoltaic, at plant/US U)
0.1% waste (Electricity from waste, at municipal waste incineration plant/CH S)

Glossary

Cluster analysis - a method that determines patterns across multiple variables in complex datasets (Wirfält & Robert 1997). Within a dataset describing dietary intakes of population, cluster analysis establishes dietary patterns and clusters observations (respondents) into groups.

Dietary cluster - a group of people with similar food preferences and consumption patterns.

Dietary recall (24-hour recall) – a method used for surveys that includes remembering and documenting items consumed on the previous day.

Environmental footprinting (environmental footprint analysis) – a process of measuring the environmental impact caused by an individual, product, system or activity (EPA, n.d. -a). In the present study the concept is related to the carbon footprinting, i.e. measuring the greenhouse gas emissions associated with the activity.

Food basket - a set of commonly consumed food items for a daily or annual individual consumption which is developed based on typical food intake among people identified as being in the particular dietary cluster.

Food consumption patterns - a repeated behavior by population groups in choosing the types, amounts and combinations of various foods. They may differ based on personal preferences, ethnic, religious and cultural background, convenience, nutritional requirements, financial situation or availability (Gerbens-Leenes & Nonhebel, 2002).

Life Cycle Assessment – a 'compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle': from raw material extraction to the product's disposal (ISO 14040).

Nutrition ecology – a concept describing nexus of nutritional and environmental research. This term has been in use from the late 1970s, and encompasses the whole food chain, encouraging the linkage between health, environment, society and economy in researching sustainable diets, sustainable food production and consumption (Baroni, Cenci, Tettamanti, & Berati, 2007).

Omnivorous diet – a dietary pattern that is based on the consumption of plant- and animal-based foods.

Pescetarian diet – a dietary pattern that is based on the food consumption that excludes meat products, but includes fish.

Sustainable diet – an overarching concept describing multidimensionality of food consumption and taking into account agriculture, social, economic and environmental well-being, nutritional value and food security (Johnston, Fanzo, & Cogill, 2014). The concept was originally introduced by Gussow and Clancy in 1986 (Gussow & Clancy, 1986), however, did not get widespread interest and support due to industrialization and globalization of food supply and agriculture (Johnston et al., 2014). A sustainable diet is viewed as socially acceptable and culturally appropriate, accessible, environmentally-friendly, affordable and nutritious (FAO, 2010b; Johnston et al., 2014; Lang, 2012).

Vegan diet – a dietary pattern that is based on the consumption of only plant-based foods. The milk is often substituted by oat-based (Risku-Norja, Kurppa, & Helenius, 2009) or soy-based milk. Meat and fish are substituted by the increased amount of vegetables, nuts and legumes to meet protein intake requirements and more calcium-rich vegetables are introduced to balance the calcium intake (van Dooren, Marinussen, Blonk, Aiking, & Vellinga, 2014).

Vegetarian (lacto-ovo vegetarian) diet – a dietary pattern that is based on the consumption of plant-based foods and some animal-based products such as egg and dairy.

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