# Integrating Sustainability and Nutrition through Dietary Pattern Optimization: A Life Cycle Assessment of Canada's Food Guide

by

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## Author's Declaration

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

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# Abstract

**Keywords:** Life Cycle Assessment, Linear Optimization, Dietary Guideline, Canada's Food Guide, Dietary Patterns, Global Warming Potential

An ideal diet should meet nutritional needs, promote health, while have less of an environmental impact. Recent studies have highlighted the significance of environmental impacts of food consumption in the context of climate change. However, research examining the environmental impacts of dietary choices in Canada is limited. The 2019 Canada's Food Guide (CFG), despite being the official and most authoritative food guide in Canada, does not evaluate its environmental impacts. Furthermore, existing studies on sustainable diets often rely on hypothetical dietary patterns (DPs), lacking real-world data on Canadians' dietary intake.

This study aims to address these gaps by (1) evaluating the environmental impacts and nutritional aspects of dietary patterns (DPs) based on the 2019 CFG for Ontarian adults from linear optimization, (2) comparing the nutrition quality and environmental impacts of these optimized diets with those of Ontario average consumption from the 2015 Canadian Community Health Survey – Nutrition (CCHSN) and National Nutritious Food Basket (NNFB), and (3) exploring the trade-offs between nutrition and multiple environmental impacts. The Nutrient Rich Foods Index 9.3 (NRF 9.3) was applied to assess nutrition quality, and Life Cycle Assessment (LCA) was used to evaluate global warming potential (GWP), eutrophication (EU), and water footprint (WF) from farm to fork.

Results showed that optimized diets significantly reduce meat and dairy intake while increasing plant-based proteins. Optimized diets achieved a 36.1% to 51.1% reduction in GWP (3.2-4.1 kg $CO_2$ eq) and a 34.3% to 54.2% reduction in EU compared to the Ontario average consumption, while maintaining a high nutritional quality. However, the study also identified trade-offs, such as an increased WF due to the higher inclusion of water-intensive foods like nuts. This research contributes to the development of dietary guidelines that align with both human health and planetary boundaries, providing valuable insights for future updates to the CFG and informing policy decisions aimed at fostering healthier and more sustainable food systems. However, the study is limited by the data availability and the focus on specific environmental impact categories. Future studies should explore a broader range of food items as well as

environmental indicators, expand to other regions in Canada, and consider the cultural and economic factors that influence food choices. Overall, this research contributes to a more comprehensive understanding of the environmental impacts of food consumption in Canada and supports efforts to promote sustainable food systems.

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# List of Abbreviations

| | |
|---|---|
| LO | Linear Optimization |
| CFG | Canada's Food Guide |
| DP | Dietary Pattern |
| CCHSN | Canadian Community Health Survey - Nutrition |
| NNFB | National Nutritious Food Basket |
| GHGE | Greenhouse Gas Emissions |
| GWP | Global Warming Potential |
| EU | Eutrophication |
| WF | Water Footprint |
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# Chapter 1 Introduction

## 1.1 Background

A nutritious diet is essential for good health and well-being (WHO, n.d.). To assist people in following a healthy diet and promote Canadians' nutritional health, the Canada Food Guide (CFG) was created and first published in July 1942 with the title of Canada's Official Food Rules (Health Canada, 2007). Over the years, the food guide has been modified many times to integrate new nutritional knowledge while maintaining the same goal of improving public health. For example, the 1942 Canada's Official Food Rule focused on wartime food rationing, while the 1961 Canada's Food Guide broadened the food choices due to improved food processing, storage, and transportation (Health Canada, 2007). The latest version of the CFG released in October 2019, emphasizes eating a variety of healthy foods each day and developing good eating habits. This latest version has been extensively studied in academic literature, focusing on nutrition assessment, the evaluation of Canadians' eating behaviors, and impacts on certain chronic diseases (Brassard et al., 2022; Corkum et al., 2022; Fernandez et al., 2020; Hamamji et al., 2022; Harrison et al., 2019; Ramuscak et al., 2022).

In conjunction with the 2019 CFG, Health Canada also developed the National Nutritious Food Basket (NNFB) to assess the affordability of healthy eating in Canada (Health Canada, 2020). The NNFB serves as a measure of cost of a diet that meets the nutritional needs of Canadians. It includes a standardized set of food items with quantities specific to different age and gender groups. The NNFB provides valuable insights into the affordability of nutritious food that can help improve food security and nutrition across the country.

On a global scale, food systems utilize enormous amounts of water, energy, chemicals through the whole process from farm-to-fork, and finally to waste (Kaplan, 2010) and account for approximately one-third of all greenhouse gas emissions (GHGE) (Crippa et al., 2021). In Canada, the agricultural sector alone contributed 10% of the nation's total GHGE in 2020, with animal production responsible for more than half of these emissions (Environment and Climate Change Canada, 2022). Ontario, as Canada's most populous province with over 15 million residents (Statistics Canada, 2024), plays a pivotal role in the nation's food system. The province's agri-food sector is a cornerstone of its economy, contributing significantly to both employment and GDP. Ontario's diverse agricultural landscape produces a wide range of food products, from livestock

and dairy to grains and fruits, making it a key player in Canada's overall food production and supply chains. However, like the rest of Canada, Ontario faces significant challenges related to the environmental sustainability of its food system. The agriculture sector in Ontario contributed to 8% of the province's GHG emissions and nearly 20% of Canada's total (Environment and Climate Change Canada, 2022).

The growing environmental pressures highlight the need for a sustainable food system that balances nutritional adequacy with reduced environmental impact. Research is increasingly focusing on sustainable diets by integrating nutrition, agriculture, food systems, and environmental science. The goal is to develop policy recommendations that promote healthier and more sustainable food systems (Johnston et al., 2014).

### 1.2 What is LCA

Life Cycle Assessment (LCA) is a widely used and standardized methodology for evaluating the environmental impacts of a product, process, or system throughout its entire life cycle, from raw material extraction (cradle), through production, distribution, and use, to disposal (grave) (ISO, 2006). The LCA framework helps quantify environmental impacts and resources used such as GHGE, water use, land use, and energy consumption, which are crucial for understanding the full scope of a product's impact on the environment (Finnveden et al., 2009).

In the context of food systems, LCA is used to assess the environmental impacts associated with each stage of the food supply chain, including agricultural production, processing, packaging, transportation, and consumption (Heller & Keoleian, 2015). The comprehensive evaluation helps identify environmental "hotspots" where the most significant impacts occur. Moreover, LCA can be employed to compare different dietary patterns (DPs) and food choices, offering insights into how shifts in diet could reduce environmental impacts, making it an essential tool for developing sustainable diets (Heller et al., 2013).

As the demand for sustainable food systems grows, the LCA framework is increasingly applied to food policy and dietary guidelines to ensure that environmental sustainability is incorporated alongside nutritional adequacy (Notarnicola et al., 2017). By using LCA, this study aimed to evaluate the environmental impacts of DPs that adhere to the 2019 CFG and identify potential trade-offs between nutrition and sustainability.

## 1.3 Research Problem

Despite the critical role of dietary guidelines in shaping public eating habits, the 2019 CFG has been criticized for its limited consideration of environmental sustainability (Lee et al., 2017; Toronto Board of Health, 2019). As the most recent and authoritative food guide for Canada, the 2019 CFG has the potential to significantly influence people's eating patterns. However, its environmental impacts remain unevaluated, mainly due to the lack of data to support recommendations on sustainability of foods. Similarly, there is no study focusing on the environmental impacts associated with the NNFB.

To date, most studies have used highly simplified hypothetical DPs to provide insights into environmental impacts. For instance, a previous study in Canada formulated low-carbon DPs using data from the 2004 Canadian Community Health Survey to meet the 2007 CFG (Veeramani et al., 2016). However, most sustainable diet studies often focus exclusively on global warming impacts, missing out on potential trade-offs across different environmental impact categories (Auestad & Fulgoni, 2015; Jones et al., 2016). This narrow focus is insufficient for a comprehensive assessment of dietary sustainability.

The severity of environmental issues has given rise to the field of sustainable diet research, which seeks to promote healthy and environmentally sustainable food choices while reducing the negative impacts of food systems on the environment and society. Besides environmental impacts, nutrition is another key factor in sustainable diets. The FAO has called for nutritional sustainability, emphasizing the need for diets that are not only environmentally sustainable but also nutritionally adequate. Consequently, there's an increasing amount of research focusing on the nutrition quality assessment of sustainable diets (Drewnowski et al., 2021; Green et al., 2020; Ocké, 2013). Current Canadian food consumption patterns reveal significant issues, including the overconsumption of certain nutrients and deficiencies in others (Prowse et al., 2022). Addressing these nutritional imbalances is essential for promoting public health and achieving truly sustainable diets.

## 1.4 Research Objectives

To summarize, it is critical to address both environmental sustainability and nutrition for sustainable diets. Thus, this study aims to evaluate the environmental impacts and nutritional aspects of DPs that follow the 2019 CFG for Ontarian adults. Specifically, linear optimization

(LO) will be used to develop DPs based on common eating patterns, and the nutrition quality and environmental impacts of these optimized diets will be compared to those of the Ontario average consumption and the NNFB. The study will also explore the trade-offs between nutrition and multiple environmental impacts, with the main focus on GWP.

## 1.5 Significance of the Study

This research aims to inform the future development of the Canada Food Guide and provide suggestions for relevant food system policies. The insights gained from this study have the potential to align the Canadian food system with both Canada's climate targets and the United Nations Sustainable Development Goals (SDGs), promoting a more sustainable and environmentally responsible approach to food and nutrition. By offering a deeper understanding and enlightenment on these critical issues, this research has the potential to drive positive change in the Canadian food system. Additionally, with a growing interest in the environmental impacts of DPs, this research will provide valuable insights for nutritionists, dietitians, and other stakeholders in the food industry. It will also help consumers to better understand the connection between their food choices and the impact on their nutritional health and the environment.

## 1.6 Thesis Structure

This chapter provided the background and context for the study. Chapter 2 presents the literature review of concepts relevant to sustainable diet studies as well as the methodology of LCA and LO. Chapter 3 includes a manuscript of the nutritional assessment and LCA for four optimized DPs based on the 2019 CFG for Ontarian adults compared to the Ontario average consumption from the 2015 Canadian Community Health Survey – Nutrition (CCHSN) and the National Nutritious Food Basket (NNFB). Chapter 4 presents the conclusions for this research and recommendations for future research and decision-makers.

# Chapter 2 Literature Review

The aim of this literature review is to provide a comprehensive survey of research on diet-related topics, identify the gaps in the sustainable diet literature, particularly in the methodology of LCA and LO in diet-related studies, and within Canada situated in a global context, since 2015. Previous LCA-related literature published prior to 2015 has already been analyzed in detail in Veeramani (2015) and Topcu (2015).

## 2.1 Application of Life Cycle Assessment in Food and Dietary Studies

LCA has emerged as a critical tool in diet-related environmental impact studies due to its standardized methodology, flexibility, and comprehensiveness (Heller et al., 2013). Beyond LCA, some studies use economic input output LCA (EIO-LCA) which builds the life cycle inventory stage based on inter-industry financial transactions of pollution discharges and the consumption of non-renewable resources (Weber & Matthews, 2008; Virtanen et al., 2011; Sherwood et al., 2017). EIO-LCA is more appropriate for "top-down" assessments of aggregates rather than detailed exploration of dietary choices (Heller et al., 2013). Given its application to a wide range of inquiries concerning diverse products and service systems, LCA remains the dominant methodology for environmental impact assessment (Heller et al., 2013). In Canada, LCA was initiated by industry with the focus on packaging and waste of raw materials (Young, 2003). But as the environmental issues are getting more attention, there is an increased application of LCA for food-related research (Arsenault et al., 2009; Pelletier et al., 2009; Beauchemin et al., 2010; Geough et al., 2012; Pelletier, 2017; Veeramani et al., 2017; Dias et al., 2017; Bamber et al., 2022).

### 2.1.1 Defining the Functional Unit (FU) in Food and Dietary Studies

In LCA, FUs are used to quantify the function of the system. The choice of FU depends on the parameters of LCA such as goal and scope, system boundaries, internal or comparative, and intended audience (Heller et al., 2013). Food serves various roles beyond its primary function of nutrition, such as providing energy, pleasure, and socio-cultural value, all of which are essential to human well-being. In most food related LCA studies, weight or volume is used as the reference flow because it is suitable for identifying system hotspots or evaluating alternative production methods (Heller et al., 2013).

While weight or volume measurements can be used to compare the environmental impacts of similar food items, they fail to capture the diverse nutritional contributions of different foods in a diet. Therefore, for the evaluation of different foods that serve different nutritional roles in a diet, a nutritionally based FU is required (Heller et al., 2013; Saarinen et al., 2017). However, this approach also has limitations, as a single nutrition indicator may not fully represent the comprehensive nutritional quality of foods or diets. The increasing academic focus on the nexus between food, diet, health benefits, and environmental sustainability has yet to yield consistent FUs. This diversity in FUs can lead to different results and thus some studies may provide misleading estimates due to the complex relationship between the nutritional content and the mass of food (Jolliet, 2022; Veeramani, 2015). Furthermore, the inconsistency of parameters in LCA studies leads to challenging generalization when comparing results from different studies (Heller et al., 2013). Overall, the FU is considered as a persistent methodological challenge in food LCAs.

### 2.1.2 Establishing System Boundaries

When conducting LCA of food or diet, it is important to define system boundaries that align with the study's objectives. Given the complexity and numerous stages in food production, accounting for the entire life cycle can be challenging. Therefore, most LCAs of food or diet typically focus on "cradle to farm-gate" or "cradle to distribution-gate" stages, as these are where most environmental impacts occur. Pre-farm activities account for roughly 40% of energy use in food production (Heller & Keoleian, 2003), while agricultural processes contribute to about 70% of climate change impacts (Virtanen et al., 2011). In terms of distribution, transportation is responsible for approximately 11% of GHGE, but the actual impact depends on the transportation mode and distance (Weber & Matthews, 2008).

The consumption stage including household processes, storage, and food waste, also plays a significant role in environmental impacts. It is estimated to account for 32% of total energy use and 10-14% of GHGE (Heller et al., 2013; Muñoz et al., 2010). However, this stage is often excluded in the literature due to the variability of consumer behaviors and data gaps. Factors such as cooking methods, locations, and personal preferences introduce significant uncertainties regarding the energy required for food processing at the household level (Walker et al., 2019).

In conclusion, for LCA studies of food, it is critical to define the system boundaries that align with the research objective. While LCAs typically focus on stages with the highest

environmental impacts, the consumption phase, despite its significant effects, is often ignored due to data limitations and the variability in consumer behavior. Overall, conducting LCA studies of food and diet requires careful consideration of various factors and potential limitations.

### 2.1.3 Selection of Environmental Impact Categories

Food production and consumption have a significant environmental impact, which is typically measured in terms of various impact categories such as global warming potential (GWP), energy use, land use, water use, eutrophication (EU), human toxicity, biodiversity loss, and others. Despite the importance of considering multiple impact categories, current literature on food impact assessment is limited in this regard. In Canada, most studies focus only on carbon footprints, as seen in Beauchemin et al. (2011), McGeough et al. (2012), and Kpogo et al. (2021). A broader range of impact categories, including resource depletion, water acidification, EU, ozone depletion, and others, are covered in other studies (Keyes et al. 2015; Dias et al., 2016; Sanderson et al., 2019; Withanage, 2020). However, due to the lack of reliable data for specific and detailed impact categories such as human toxicity and EU, the lack of complete consideration of the environmental impacts of food production and consumption is considered as a gap (Cucurachi et al., 2019; Topcu et al., 2022; Veeramani et al., 2017).

## 2.2 Analysis of DPs and Consumption Data

The United States Department of Agriculture defines a DP as the types and amounts of foods, beverages, and nutrients that are typically consumed, and their frequency (USDA, 2014). For diet-related research, researchers may use either actual food consumption data or hypothetical DPs to assess and achieve optimal nutrition, depending on the availability of data and the goals of the study (Heller et al., 2013). Common methodologies for determining actual food consumption include food balance sheets, 24-hour dietary recalls, food frequency questionnaires (FFQ), food records, etc. (Bailey, 2021; Medlin & Skinner, 1988). In Canada, population-level food consumption is reported in the Canadian Community Health Survey (CCHS). The development of hypothetical DPs can be accomplished using resources such as scientifically validated healthy diets (e.g. the Dietary Approaches to Stop Hypertension diet, Mediterranean diet, flexitarian diet, etc.), healthy eating indices, food availability data, and national dietary guidelines.

Self-reported food intake assesses actual food consumption and can be easy to administer to large populations, but it is subject to limitations such as recall bias, social desirability bias, lack

of knowledge, and misreporting (Bingham, 1991; Subar et al., 2015; Ravelli & Schoeller, 2020). In contrast, hypothetical DPs can provide easily communicated results, but may not account for real-world factors such as cultural or social acceptability and practical implementation (Perignon & Darmon, 2021). In sustainable diet studies, the hypothetical approach is more commonly used due to its ease of data collection and analysis. Collecting actual food intake data can be time-consuming and tedious, and data management and analysis can also be challenging (Perignon & Darmon, 2021). Both approaches have their respective advantages and limitations so that the choice of approach should be guided by the research question and the need to balance precision, practicality, and feasibility.

## 2.3 Overview of Dietary Recommendations

### 2.3.1 National Dietary Guidelines - Canada's Food Guide

Canada's Food Guide (CFG) has evolved significantly since its inception in 1942, reflecting the changing dietary needs, scientific understandings, and cultural preferences of the Canadian population (Health Canada, 2007). Initially introduced as "Canada's Official Food Rules" during World War II, its primary aim was to maximize nutrition among Canadians despite wartime food rationing and poverty. The guide experienced its first transformation in 1944 as the "Canada's Food Rules", responding to shifts in food supply and improvements in nutrition science (Health Canada, 2007). Through multiple revisions to reflect contemporary nutritional research and public health advice, the guide was renamed in 1961 as "Canada's Food Guide", embracing the flexibility and variety of healthy eating (Health Canada, 2019). The most recent version, launched in 2019, marked a significant shift towards a more holistic approach to nutrition. It moves away from strict serving sizes to a focus on the balance, variety, and quality of food, promoting mindful eating among Canadians.

The extensive research on the CFG following its 2019 revision presents a diverse understanding of its public perception and health impacts. The literature also addresses affordability, eating behaviors, consumption patterns, and the development of CFG-related assessment tools. Despite the widespread awareness, the 2019 CFG's influence on people's dietary choices changes remains limited (Zhao et al., 2023). Obstacles to CFG implementation include confusion over specific details or terminology, such as food groups, food categorization, and recommended proportions (Ramuscak et al., 2023; Zhang et al., 2022), as well as practical

challenges like food affordability, time constraints, and a lack of cooking skills (Leme et al., 2022; Hank et al., 2023; Laila et al., 2023; Rochefort et al., 2023). These findings suggest a need for improved engagement and education strategies (Corkum et al., 2023; Laila et al., 2023). Additionally, the 2019 CFG lacks specific guidance tailored to vulnerable groups such as indigenous people, children, pregnant women, and the elderly (Fernandez et al., 2020; Patel & Mannion., 2021). As a result, the new CFG, although based on best available nutrition and health science, faces challenges in implementation.

The positive health impacts of the 2019 CFG are profound. Greater adherence to the 2019 CFG recommendations is associated with improved and adequate nutrient intake for most of the key nutrients (Brassard & Chevalier., 2023), a lower risk of cardiovascular disease (Brassard et al., 2023), and a reduction in saturated fats intake (Harrison et al., 2022). However, there remain concerns about the pro-inflammatory potential (Pfisterer et al., 2023) and nutritional inadequacy of calcium and vitamin D intake of diets based on 2019 CFG (Barr, 2019). To contribute to a more comprehensive approach to dietary assessment and guidance, assessment tools have been developed to measure the adherence to 2019 CFG, including the Canadian Eating Practice Screener, which assesses people's eating behaviors (Perreault et al., 2023; Wallace et al., 2023), the Canadian Food Intake Screener, which assesses the alignment of adults' dietary intake (Hutchinson, 2023), and the Healthy Eating Food Index (HEFI)-2019 (Brassard et al., 2022).

In contrast, there are limited studies focusing on the environmental considerations of the 2019 CFG. The singular study available evaluates how the Canadian food supply aligns with both the 2019 CFG and the EAT-Lancet diet, which considers environmental impacts, suggesting that compliance with dietary guidelines could notably decrease environmental impacts (Abe-Igne et al., 2024). This gap in research highlights the importance of further exploring the environmental impacts of the DPs recommended by the 2019 CFG, particularly how they might be optimized to support human health.

### 2.3.2 A Global Framework for Sustainable Eating - The EAT-Lancet Diet

The EAT-Lancet Diet, also known as the Planetary Health Diet, was introduced by the EAT-Lancet Commission in 2019. The Commission developed this revolutionary diet using the concept of planetary boundaries as guidelines for environmentally sustainable consumption. The ultimate goal is to create a sustainable food system that can nourish a growing population without

compromising the health of the planet. It recommends a large intake of fruits, vegetables, nuts, legumes, and unsaturated oils, a moderate consumption of seafood and poultry, and minimal amounts of red meat, processed meat, added sugar, refined grains, and starchy vegetables (Willett et al., 2019).

Nevertheless, the complex interplay of health, nutrition, and environmental sustainability has sparked criticism of the EAT-Lancet Diet, highlighting the limitations of a "one-size-fits-all" solution (Verkerk, 2019). Other critiques include concerns about the affordability of the EAT-Lancet diet (Drewnowski, 2020; Hirvonen et al., 2020); potential micronutrient inadequacies for vitamin B12, calcium, iron, and zinc due to decreased consumption of animal-sourced foods (Beal et al., 2023); and its insufficient support for brain health due to inadequate levels of protein, selenium, zinc, iron, and folate, which could negatively affect mood (Young, 2022). Furthermore, the diet's effectiveness in non-communicable disease mortality prevention has been questioned (Zagmutt et al., 2020), along with concerns regarding the quality and transparency of underlying data and assumptions used for the development of the EAT-Lancet diet (Stanton, 2024). As a result, although the EAT-Lancet diet offers a groundbreaking framework to navigate the intricate relationship between human health, nutrition, and environmental sustainability, there remains considerable room for refinement.

Research on the environmental impacts of the EAT-Lancet diet suggest its significant potential in reducing dietary environmental impacts as demonstrated by extensive studies in high-income countries including Denmark (Geibel & Freund, 2023; Prag & Henriksen, 2020), France (Kesse-Guyot et al., 2021), Germany (Vallejo et al., 2022), Italy (Mangone et al., 2023; Vitale et al., 2021), the Netherlands (Colizzi et al., 2023), New Zealand (Cleghorn et al., 2022; Reynolds et al., 2022), Spain (Cambeses-Franco et al., 2022), Sweden (Colombo et al., 2021), United Kingdom (Bellamy et al., 2023; Stewart et al., 2023; Sun et al., 2022), and the USA (Stone et al., 2023). These studies show that greater adherence to the EAT-Lancet diet is associated with significant reductions in GHGE, land use, and possibly water use and energy demand. However, its adoption would have varying environmental impacts, particularly between high-income and low-income countries (Semba et al., 2020). For instance, while adopting EAT-Lancet diet greatly contributes to nutrition sufficiency, it can inadvertently lead to increased GHGE compared to the current baseline diets in developing countries such as China, due to increased consumption of aquatic products (Guo et al., 2022), and Indonesia, due to increased dairy product intake (de Pee et al.,

2021). This highlights the demand for country-specific environmental evaluations in future research related to the EAT-Lancet diet. Moreover, the existing literature primarily addresses GHGE and land use, leaving a gap in the assessment of the full range of environmental indicators. Comprehensive data is necessary to fully understand the global environmental implications of the EAT-Lancet diet. To date, no research has been conducted on the environmental effects of adopting the EAT-Lancet Diet in Canada.

## 2.4 Assessing the Environmental Impacts of Food Consumption

### 2.4.1 Environmental Impact of Specific Food Products

There is a growing body of knowledge on the life cycle environmental impacts of various food items, including meat, dairy products, whole grains, fruits and vegetables, beverages, and even condiments (Nemecek et al., 2016; Perignon & Darmon, 2021). In Canada, there are LCA studies on: GHGE from beef production in western Canada (Beauchemin et al., 2011); GHGE from dairy production in eastern Canada (Arsenault et al., 2009; McGeough et al., 2012); a range of environmental impacts from winemaking in Nova Scotia (Point et al., 2012); energy use and environmental impacts in conventional and organic apple production in Nova Scotia (Keyes et al. 2015); environmental impacts for greenhouse-grown tomato production in Ontario (Dias et al., 2016); environmental impacts of Okanagan cherries (Sanderson et al., 2019); acidification, global warming, ozone depletion, resources depletion, and EU of fresh and frozen broccoli in Ontario (Withanage, 2020); and GHGE from pork fed with high wheat millrun (Kpogo et al., 2021). Environmental impact assessment of a single food item cannot fully represent food consumption patterns, as foods are rarely consumed in isolation. However, these studies provide valuable insights that can lead to improvements in food production. Additionally, they serve as building blocks for more comprehensive studies that take into account broader consumption patterns (Heller et al., 2013).

### 2.4.2 Environmental Impacts of Aggregated DPs

A stronger basis for connecting nutrition quality and environmental impacts can be established through diets that consist of multiple food items (Heller et al., 2013). Taking a holistic approach to assessing diets can provide a more accurate picture of their environmental impact. To date, a large body of literature has examined the environmental impacts of diets from different regions all around the world. Studies in the last ten years have been conducted in Australia

(Hadjikakou, 2017), Canada (Veeramani, 2015, 2016, 2017; Auclair & Burgos, 2021; Topcu, 2022), Denmark (Werner et al., 2014), Europe (Walker et al., 2019; Mertens et al., 2019), Greece (Abeliotis et al., 2016), India (Green et al., 2019), the Netherlands (Temme et al., 2013, 2015; Van Dooren et al., 2015; Tyszler et al., 2016), New Zealand (Wilson et al., 2013), the Nordic region (Röös et al., 2015; Jensen et al., 2015), Peru (Vazquez-Rowe et al., 2017), Spain (Batlle-Bayer et al., 2020; Esteve-Llorens et al., 2020), Sweden (Hjorth et al., 2020), the United States (Daniel et al., 2011; Marlow et al., 2015; Rose et al., 2019; Chapa et al., 2020), and many other locations. The environmental impacts of diets vary widely among countries because different countries focus on different dietary concerns (Behrens et al., 2017), and culture influences food consumption.

Research has demonstrated that a healthy diet does not necessarily correspond to low environmental impacts (Macdiarmid, 2013). As environmental issues become more urgent, studies are increasingly investigating the environmental impacts of recommended health-optimizing diets. For example, research has explored the environmental impact of the Mediterranean diet (Castañé & Antón, 2017; Serra-Majem et al., 2020; Grosso et al., 2020; Tsiampalis et al., 2021; Vinci et al., 2022), the DASH diet (Monsivais et al., 2015; Perignon et al., 2017), and the flexitarian diet (Hicks et al., 2018; Springmann et al., 2018; Green et al., 2022; Jansson et al., 2022). These studies provide valuable insights into the complicated and nuanced relationship between nutrition and sustainability, as well as the trade-offs that are often required to balance these two factors.

To provide guidance for the general public to achieve and maintain a healthy diet, national dietary guidelines are developed by national agencies and organizations based on scientific research. However, national dietary guidelines typically only address health benefits of various food and DPs, without discussing the environmental impact of diets (Behrens et al., 2017). The academic community has recognized this gap, and research is being conducted to investigate the environmental impact of national dietary guidelines in various countries, including Argentina (Arrieta & Gonzalez, 2018), Australia (Selvey & Carey, 2013), Brazil (Monteiro et al., 2015), France (Kesse-Guyot et al., 2020), Qatar (Seed, 2015), New Zealand (Jones et al., 2019), Spain (Batlle-Bayer et al., 2019), Sweden, Netherlands, UK, and China (Behrens et al., 2017). Despite this growing body of research, only one study has explored the role of the 2007 Canada Food Guide in the global warming impacts of diets (Veeramani, 2015). It is increasingly important to consider the environmental impact of dietary recommendations to promote both personal health and the health of the planet.

Diet-related studies commonly compare the composition of animal-based and plant-based proteins. It has been demonstrated consistently that animal-derived foods generally have higher environmental impacts than plant-based proteins (Pimentel & Pimentel, 2003; Berners-Lee et al., 2012; Heller et al., 2013; Rosi et al., 2017; Espinosa-Marrón et al., 2022). Among animal-derived foods, red meat is widely recognized as a top contributor to environmental impacts, particularly in terms of GHGE (Wolk, 2017; Godfray et al., 2018; González et al., 2020; Coffey et al., 2022). While transitioning from animal-based to plant-based proteins can lead to significant health benefits, it is important to recognize that such a shift can also result in higher environmental impacts through excessive land use, soil pollution, water depletion, and air pollution. Therefore, it is crucial to consider the balance and proportion of different food items within a DP.

Diet-related environmental assessments can be based on both hypothetical and actual food consumption. Hypothetical diets are often constructed based on recommended DPs or national dietary guidelines (Friel et al., 2014; Rosi et al., 2017; Barnsley et al., 2021). They offer greater flexibility and allow for the exploration of a wide range of scenarios, but may oversimplify the complex social, cultural, and economic factors that influence food choices, and may not accurately reflect real-world dietary behaviors. Findings from studies based on hypothetical diets may also be limited by differences in cultural structures and geographic regions. In contrast, realistic diets, based on actual food consumption, are often used to compare recommended DPs and the findings can stimulate future research and policy change. However, realistic diets may also be limited by incomplete or inaccurate data. Therefore, it is important to consider the targeted diet based on the goal for the study.

In conclusion, studies on the environmental impacts of food consumption have evolved from analyzing individual food items to assessing diets as a whole, with a growing body of literature emphasizing the complex relationship between nutrition and sustainability. While animal-derived foods, particularly red meat, have been found to have higher environmental impacts than plant-based foods, there are exceptions that perishable fruits and vegetables transported by airplanes and those grown in greenhouses can also have severe environmental impacts (Heller et al., 2013). As environmental issues become more urgent, it is essential for national dietary guidelines to integrate both health considerations and environmental impacts in promoting sustainable food choices.

## 2.5 The Role of Linear Optimization in Dietary Studies

Linear Optimization (LO), also known as linear programming, is a mathematical method that creates optimal solutions that simultaneously meet a series of constraints (Dantzig & Thapa, 2013). In diet-related studies, it has played a crucial role in optimizing diets by addressing nutritional, economic, and environmental considerations. Its roots trace back to the "Diet Problem" during World War II, which sought cost-effective nutrition for U.S. soldiers (Smith, 1959). The development of LO solutions for dietary problems has significantly advanced since 2000, with the advent of powerful computing technologies and sophisticated tools (van Dooren, 2018). From individual diet optimization to addressing comprehensive issues like food aid and national dietary guidelines, LO has showcased its capability in tackling a range of diet-related challenges (van Dooren, 2018). Different studies can have different objectives with specific sets of constraints for LO such as optimizing nutrition, minimizing environmental impacts, or minimizing deviations from current diet.

The research using LO in diet studies has evolved to address complex challenges of balancing nutrition, cost, sustainability, and diet acceptability. Various studies would employ different goals and constraints. Early works from Ferguson et al. (2004) and Darmon et al. (2009) laid the groundwork by using LO to effectively develop and validate dietary guidelines. Subsequently, Maillot et al. (2008, 2010) expanded the focus to include the dynamics between nutrition, cost, and cultural acceptability within the French dietary context. This emphasis paved the way for incorporating broader sustainability concerns. As environmental impacts of food consumption gained attention, studies began to link dietary choices with sustainability, particularly GHGE, demonstrating that high nutritional quality often correlates with higher emissions (Vieux et al., 2013) while minimizing environmental impacts and fulfilling nutrition recommendations is feasible (von Ow, et al., 2020). Chaudhary & Krishna (2019) and Walker et al. (2021) presented a nuanced approach to configure diets that meet nutritional needs within the planetary boundaries for environmental domains, advocating for season- and country-specific dietary solutions. A study in Sweden highlighted the disparity between sustainability-optimized diets and the EAT-Lancet diet, calling attention to the necessity for localized dietary solutions (Colombo et al., 2021).

Recent studies have been using more comprehensive LO approaches. Research from Germany (Masino et al., 2023), Italy (Donati et al., 2016), Netherland (van Dooren & Aiking,

2014; van Dooren et al., 2015), New Zealand (Wilson et al., 2013), Spain (Munoz-Martínez et al., 2023), Sweden (Elinder et al., 2020), and United Kingdom (Macdiarmid et al., 2012) suggested that it is possible to build healthy, low-cost, environmentally sustainable, and sometimes culturally acceptable DPs. Notably, research from the Netherlands by Bruins & Létinois (2020) highlighted the challenge of meeting vitamin D requirements within carbon emission limits without fortified foods or supplements, offering crucial insights into the construction of nutritional constraints in LO models.

Despite the value LO has brought to diet optimization, significant gaps exist, particularly in incorporating cultural appropriateness and acceptability into the models. While consumers' acceptability is recognized in some studies, in-depth exploration into individual and local dietary preferences is required to ensure optimized diets are not just theoretically acceptable but truly feasible in practice. Environmental analyses often focus predominantly on GHGE, sometimes land and water use, but other environmental metrics should also be considered to fully understand the trade-offs involved. The variation in methodologies and constraints among studies complicates the comparison and application of results, indicating the need for more refined LO approaches that consider a wider array of constraints, and the nonlinear relationships between different dietary factors.

## 2.6 Nutritional Quality and Health Implications of Dietary Choices

Research on food and diets has predominantly centered on the health, nutrition, and social implications of dietary choices (Brassard et al., 2022; Jessri et al., 2015; Laila et al., 2023). It is well-established that diets rich in animal-based products are associated with higher risks of chronic diseases such as cardiovascular disease, type-2 diabetes, stroke, cancer, hypertension, obesity, etc. (Zhong et al., 2020). Conversely, plant-based diets have been linked to lower risks of diseases and reduced mortality rates (Tuso et al., 2013). However, it is important to recognize that plant-based diets can also result in certain nutrient deficiencies (Sakkas et al., 2020), which must be addressed for overall dietary adequacy.

Another critical factor to consider in the context of healthy and sustainable diets is the sodium content of foods. High sodium consumption is associated with an increased risk of cardiovascular disease (He et al., 1999; O'Donnell et al., 2015). Processed foods tend to have higher sodium and calorie content, making them correlated with obesity and cardiometabolic

outcomes (Poti et al., 2017). Therefore, achieving balance in food choices is essential for both health and sustainability.

Combining health considerations with environmental impacts, LCA studies of food must consider trade-offs, which include the direct effects of dietary quality on health and the indirect health consequences of exposure to emissions throughout the food life cycle (such as human toxicity), as well as the environmental impacts of different DPs. A truly sustainable diet must integrate both health and environmental factors, promoting well-being while respecting the planetary boundaries.

## Chapter 3 Contributions

The contributions for this chapter are as follows: Xuyang Guo, thesis author, conducted analysis and wrote the content, Dr. Roberto Guglielmi and William Gao provided the linear optimization platform, Basak Topcu provided the LCI database for food consumed in Ontario, Canada, while Dr. Goretty Dias and Dr. Rachel Prowse provided guidance on methods and revisions, and Basak Topcu developed the LCI database with some support from Xuyang Guo.

## Integrating Sustainability and Nutrition through Dietary Pattern Optimization: A Life Cycle Assessment of Canada's Food Guide

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### 3.1 Abstract

A nutritious diet is crucial for health and well-being. The 2019 Canada Food Guide (CFG) emphasizes a holistic approach to healthy eating, yet its environmental implications remain unexplored. This study addresses the intersection of nutrition and environmental sustainability by (1) evaluating the environmental impacts and nutritional aspects of dietary patterns (DPs) based on the 2019 CFG for Ontarian adults from linear optimization (LO), (2) comparing the nutrition quality and environmental impacts of these optimized diets with those of Ontario average consumption from the 2015 Canadian Community Health Survey – Nutrition (CCHSN) and National Nutritious Food Basket (NNFB), and (3) exploring the trade-offs between nutrition and multiple environmental impacts. The Nutrient Rich Foods Index 9.3 (NRF 9.3) was applied to assess nutrition quality, and Life Cycle Assessment (LCA) was used to evaluate global warming potential, eutrophication (EU), and water footprint (WF). Results show that optimized diets achieve excellent NRF 9.3 score and significantly reduce meat and dairy intake while increasing plant-based proteins. The optimized diets achieved 36.1%-51.1% reduction in GWP (3.2-4.1 kg $CO_2$ eq) compared to the Ontario average. However, trade-offs were noted, such as increased WF in optimized diets. This study provides insights into the development of dietary guidelines that promote both human health and planetary well-being, informing future updates to the CFG and supporting more sustainable food choices.

*Keywords: life cycle assessment, linear optimization, dietary guideline, Canada's Food Guide, dietary pattern, global warming potential*

### 3.2 Introduction

A nutritious diet is essential for good health and well-being (WHO, n.d.). To assist people in following a healthy diet and promote Canadians' nutritional health, the Canada Food Guide (CFG) was created and first published in July 1942 with the title of Canada's Official Food Rules (Health Canada, 2007). Over the years, the CFG has evolved significantly, reflecting advancements in nutritional science, changes in food availability, and shifting cultural values. The

latest version, released in 2019, emphasizes a holistic approach to healthy eating, focusing on balance, variety, and quality of food, along with the promotion of mindful eating habits. In response to concerns about the affordability of healthy diets, Health Canada also developed the National Nutritious Food Basket (NNFB) based on the 2019 CFG. The NNFB provides a standardized set of food items with quantities tailored to different age and gender groups, offering insights into the cost of maintaining a nutritious diet.

Despite these advancements, the 2019 CFG has faced criticism for its limited consideration of environmental sustainability. This is a significant oversight given the growing awareness of the environmental impacts of food systems, which contribute approximately one-third of global greenhouse gas emissions (GHGE) (Crippa et al., 2021). In Canada, the agricultural sector is responsible for 10% of the country's total GHGE, with a substantial portion of these emissions stemming from animal production (Environment and Climate Change Canada, 2022). As the urgency to address climate change intensifies, there is a pressing need for dietary guidelines that not only promote nutritional health but also minimize environmental impacts.

The relationship between dietary patterns (DPs) and environmental sustainability has been the focus of a growing body of research, particularly through the application of LCA methodologies. LCA provides a comprehensive framework for assessing the environmental impacts of food production and consumption, taking into account factors such as global warming potential (GWP), land use, water use, and energy consumption. Studies have applied LCA to both individual food items and entire DPs, consistently revealing that animal-based foods are key "hotspots" for environmental impacts, typically contributing more to GWP, land use, and water consumption compared to plant-based foods (Heller et al., 2013: Nemecek et al., 2016; Poore & Nemecek, 2018). However, there are exceptions, such as perishable fruits and vegetables transported by air or grown in heated greenhouses, which can also have substantial environmental footprints (Heller et al., 2013). This suggests that while animal-based foods are generally recognized as the primary contributors to environmental impacts, some plant-based foods can also carry substantial burdens depending on their production and transport methods.

Despite the insights provided by LCA, most research in this area has focused narrowly on GWP, often neglecting other critical environmental impact categories such as EU, WF, and biodiversity loss. The narrow focus on GWP overlooks the full range of environmental

consequences associated with food systems. Additionally, many studies rely on hypothetical DPs that may not fully capture the complexities of real-world diets, including cultural acceptability and practical implementation challenges (Perignon & Darmon, 2021). These gaps highlight the need for more comprehensive assessments that consider multiple environmental impacts and the trade-offs between them.

LO has emerged as a valuable tool in the development of sustainable DPs. LO allows researchers to create optimized diets that meet specific nutritional, economic, and environmental goals while adhering to various constraints. Studies using LO have demonstrated that it is possible to design diets that are nutritionally adequate, low-cost, and environmentally sustainable (Darmon et al., 2009; van Dooren, 2018). However, challenges remain in incorporating cultural appropriateness and a broader range of environmental metrics into these models, underscoring the need for further refinement of LO methodologies in diet-related research.

The 2019 CFG, despite its emphasis on nutrition and health, has yet to be fully evaluated in terms of its environmental impacts. Similarly, the environmental implications of the NNFB remain largely unexplored. This study aims to address these gaps by evaluating optimized DPs based on the 2019 CFG that minimize environmental impact while maximizing nutritional quality. The research will assess the nutritional quality and environmental impacts of these optimized diets, the Ontario average diet, and the NNFB, exploring the trade-offs between nutrition and environmental impacts across different categories.

This study addresses a critical gap in the literature on sustainable dietary patterns by evaluating the environmental impacts of DPs of the 2019 CFG. This research has the potential to inform future updates to the CFG and other food system policies, aligning them with Canada's climate targets and the United Nations Sustainable Development Goals (SDGs). By providing a deeper understanding of the connections between dietary choices, nutrition, and environmental sustainability, this study aims to contribute to the development of dietary guidelines that support both human's nutritional health and the health of the planet. The insights gained will be valuable to policymakers, nutritionists, dietitians, and consumers, helping to promote more informed and sustainable food choices.

## 3.3 Methodology

In this study, LCA was conducted to quantify the environmental impacts of four optimized diet based on the 2019 CFG from LO, following the International Organization for Standardization (ISO) guidelines of ISO 14040 (2006) and ISO 14044 (2006). The analysis encompassed all stages of LCA, including goal and scope definition, inventory analysis, impact assessment, and interpretation of results. The assessment was conducted using the openLCA software.

There were three main phases. Firstly, LO was applied to generate four types of diet that incorporate the 2019 CFG: omnivore, vegetarian, pescatarian, and no red meat, based on the food items chosen from the 2015 Canadian Community Health Survey – Nutrition (CCHSN) food consumption data with multiple constraints. Secondly, the NRF9.3 score will be calculated for the optimized diets, the average Ontario consumption from the 2015 CCHSN, and the NNFB. Lastly, impact assessment was used to assess several environmental impacts of the six DPs. Goal & Scope

The goal of this LCA study was to provide quantitative perspectives on the environmental impacts of six DPs:

- Four optimized DPs based on the 2019 CFG (omnivore, vegetarian, pescatarian, and no red meat)
- The average Ontario consumption from the 2015 CCHSN
- DP based on the NNFB

This study also involved comparing the environmental impacts of these DPs to understand how each one affects the environment and evaluating the trade-offs between different FUs and among different environmental impacts, identifying where compromises might occur. And finally, the ultimate goal was to provide insights for future CFG development and promote sustainable and nutritional eating patterns.

### 3.3.1 Functional Unit (FU)

The measurement of environmental impacts using LCA involves using FUs to quantify the function of a system (Heller et al., 2016). The selection of an appropriate FU depends on various parameters of LCA, including the goal and scope, system boundaries, internal or comparative, and intended audience (Heller et al., 2013). As food serves multiple functions, such as providing

energy, nutrition, pleasure, and social or cultural value, the FU for food or diets is not always consistent in the literature.

In this particular study, the primary function of the optimized diets is to provide energy to the human body. Therefore, the selected FU for this study is 2,000 kcal, which is the recommended daily average intake for adults and youth (ages 13 and older) in Canada (Ontario Ministry of Health, 2021) as well as the reference level for daily values (DVs) in Canada (Health Canada, 2015). For comparison, Topcu et al. (2022) used a FU of 985,500 kcal, representing the actual average consumption for one Ontario resident for one year (2,700 kcal per person per day), while Veeramani et al. (2017) used a FU of 837,436 kcal, which reflects the estimated caloric requirement for one person per year (2,294 kcal per person per day). Given that individual caloric needs vary, with average intake for an adult ranging from 2,000 to 2,400 calories per day (Ontario Ministry of Health, 2021), the FU of 2,000 kcal used in this study is appropriate and reasonable.

However, diets with low environmental impacts may also have low nutritional quality (Vieux et al., 2018). In order to comprehensively evaluate the impacts of the optimized diets, this study also incorporates NRF9.3 score as an additional nutritional-based FU. Even though the NRF score was originally designed for food nutrient profiling, it has proven effective as a diet quality scoring scheme in connection with environmental impact assessments (Heller et al., 2013). This ensures that the nutritional quality of the four optimized diets is adequately assessed alongside their environmental impacts, providing a more holistic understanding of the overall benefits and trade-offs.

The NRF9.3 score is calculated as the arithmetic mean of the percentage of recommended daily intakes for nine nutrients to encourage, minus the arithmetic mean of the percentage of maximum daily value (DV) for three nutrients to limit (Drewnowski & Fulgoni, 2008). For this study, the DV values for Canada are used in the calculation. The nutrients used for the score are consistent with those used in the LO model. Typically, the NRF9.3 score is based on 100kcal, 100 grams, or a reference serving size of food (Drewnowski & Fulgoni, 2008). However, for this study, the NRF9.3 score was calculated for the food consumption meeting the nutritional-based FU can are comparable to those with the caloric-based 2000 kcal FU.

### 3.3.2 System Boundaries

In this study, the system boundaries have been established in relation to the complete farm-to-fork process including food waste and loss that occurs along the supply chain up to the consumer. Specifically, the system boundaries include production, processing, distribution, retail, and cooking stage. This comprehensive approach allows for a more systemic assessment of the environmental impacts associated with the food supply chain, from the initial stages of food production to its consumption. Based on the Ontario LCI database, the geographic boundary of the study is limited to the province of Ontario in Canada.

### 3.3.3 Impact Categories

This study aims to investigate several key environmental impact categories of the optimized diets, including GWP, EU, and WF. The TRACI 2.1 impact assessment method, which was developed by the U.S Environmental Protection Agency and provides regional environmental impact categories and characterization factors specific to North America, and Hoekstra et al. (2012), which provides a comprehensive view of water use by considering green, blue, and grey water footprints, were applied to assess the impact categories.

### 3.3.4 Life Cycle Inventory

The Life Cycle Inventory (LCI) provides a detailed account of the resource use and flow attributed to a product or process. The LCI includes data on all inputs and outputs associated with a product throughout its production stages within the defined system boundary.

#### *3.3.4.1 Four Optimized DPs from Linear Optimization*

LO is considered as a novel approach to design diets that can achieve multiple interrelated goals of nutrition, environmental sustainability, and even acceptability (Eustachio Colombo et al., 2024). In this study, LO was applied using SciPy HiGHS Linear Programming Optimizer (Huangfu & Hall, 2018; Virtanen et al., 2020) with specific constraints to design four different DPs: omnivore, vegetarian, pescatarian, and no red meat. These DPs were optimized to maximize nutrition while minimize GWP for adults in Ontario, based on a 2000 kcal daily intake. The details of the four DPs are as follows:

- Omnivore: include a variety of foods from both plant and animal sources, with no specific food exclusions or dietary restrictions
- Vegetarian: specifically lacto-ovo vegetarian that exclude meat and fish but include dairy and eggs
- Pescatarian: exclude meat but include fish, dairy, and eggs
- No red meat: exclude red meat, specifically beef and pork, but include other animal products

The vegan diet was excluded from this study because achieving sufficient levels of certain essential nutrients solely through a vegan diet has been proven to be highly challenging without fortified foods or supplementations (Craig, 2009; Rogerson, 2017). Specifically, nutrients such as vitamin B12, which is primarily found in animal products, as well as omega-3 fatty acids, iron, calcium, and vitamin D, can be difficult to obtain in adequate amounts through a vegan diet alone. This study focuses on designing DPs that can achieve nutrient sufficiency without relying on supplements or fortification, due to lack of LCI. Therefore, vegan diet was no considered in this study.

The Canadian Community Health Survey (CCHS) is a cross-sectional survey that gathers health-related information about the Canadian population, created through collaboration among the Canadian Institute for Health Information, Statistics Canada, and Health Canada (Health Canada, 2023). The first CCHS was launched in 2000 with the main aim of providing population-level data on health determinants, health status, and health system utilization (Health Canada, 2022). The most recent CCHS data, which was a focus on food and nutrition, was collected in 2015 (Health Canada, 2022). The survey performed 24-hour dietary recall for 20,487 individuals one year of age and over living in all ten Canadian provinces, with 4,229 participants in Ontario (Public Health Ontario, 2021). As the food consumption data from CCHSN enables the estimation of daily food intakes for the Canadian population, this study used this data to identify the food items and quantities incorporated in the modelled diets.

Originally, there were 119 items in the 2015 CCHSN. However, any food items that are not recommended by the 2019 CFG such as processed food (e.g., processed breakfast cereals, sweets, snacks, processed meat like sausage), sweetened beverages, saturated fat (animal fat), food with vague labels (such as Fruit_other, Other_vegetables, etc.), and food that people do not

consume directly (such as flour and corn meal) were excluded. In addition, spices are out of the scope of this research because their low amounts of consumption and data unavailability. For eggs, they were originally categorized under the dairy category, while in the LO model, eggs were classified into a separate category labeled “egg”. This adjustment was made to more accurately represent the unique nutritional characteristics of eggs within the model. Table A - 1 in Appendix A represent all the food categories and items in the original 2015 CCHNS and those used in the LO model. According to the 2019 CFG recommendation for adults (Health Canada, 2022), soy milk was added as a category of milk substitute, milk and yogurt were switched to low-fat version, and all items in the grain category (rice, bread, and bread) that were originally refined grain in the 2015 CCHSN have been replaced with whole grain versions. Finally, there are 62 items in total in the LO model.

##### 3.3.4.1.1 Volume Constraints

The 2019 CFG provides a volumetric plate-like recommendation, where fruits and vegetables take up 50% of the plate, protein food occupy 25%, and whole grains foods take up the remaining 25%. Since the LCI database is based on per kg of food, food density data need to be applied to convert the volume-based recommendation from 2019 CFG to mass-based quantities. The food density data was obtained from Health Canada’s database (Health Canada, 2008) and an online database AquaCalc which calculates food density using information from USDA FoodData Central.

In order to ensure the variety of food, additional volume constraints from the Harvard Healthy Eating Plate were applied for fruits and vegetables, specifying that 2/3 should be vegetables and the other 1/3 should be fruits to limit sugar inside the 50% portion of the plate.

##### 3.3.4.1.2 Nutrition Constraints

One of the objectives for the LO for this study is to maximize the nutrition for an adult. As mentioned in the literature review, there is no consensus on the measurement of nutritional quality for diets (Reguant-Closa et al., 2024). The Nutrient Rich Foods Index 9.3 (NRF9.3) provides a broad nutrient coverage and comprehensive nutritional assessment (Bianchi et al., 2020), making the nutrients included suitable for defining the nutrition constraints. There are 12 nutrients (nine nutrients to encourage and three nutrients to limit) from the NRF9.3. Among the original nine nutrients to encourage, vitamin E is replaced by another nutrient of interest because vitamin E

deficiency is very uncommon (Kemnic & Coleman, 2023). Initially, vitamin D was considered due to its prevalent deficiency in Canada (Schwalfenberg et al., 2010). However, achieving adequate vitamin D through diet alone, without fortified food and supplementation, is proven to be impractical and would greatly increase the carbon emission and calorie intake (Bruins & Létinois, 2021), making vitamin D unsuitable to be optimized in this study. Instead, vitamin B12 was selected as it is only naturally present in animal-origin foods, aligning with the study's interest in four different diets. The final nine nutrients to encourage included in this study are protein, fiber, vitamin A, vitamin B12, vitamin C, calcium, iron, magnesium, and potassium. The three nutrients to limit include added sugar, saturated fat, and sodium. The nutrition composition of each food item was sourced from the Canada Nutrient File (CNF) database. The final NRF 9.3 score calculation for this study is: NRF 9.3 = (protein g/50 g + fiber g/28 g + vitamin A μg/900 μg + vitamin C mg/90 mg + vitamin B12 μg/2.4 μg + calcium mg/1300 mg + iron mg/18 mg + magnesium mg/420 mg + potassium mg/3400 mg – saturated fat g/20 g – added sugars g/50 g – sodium mg/2300 mg).

Table 1 shows the complete nutrition constraints used in the LO model. The calculation of each number is represented in Table A - 2 in Appendix A. The Recommended Dietary Allowance (RDA) values are used as the lower bounds for nutrients to encourage, because they serve as the goal for usual intake for an individual (Health Canada, 2023). Since this study does not focus on gender-specific or age-specific nutrition, the arithmetic mean of RDA for females and males is calculated as the lower bound. When RDA is unavailable, the Adequate Intake (AI) is used as a replacement although they are not equivalent. The Tolerable Upper Intake Level (UL), which represents the highest average daily intake level that has no risk of adverse health effects to nearly all individuals (Health Canada, 2023), is applied as the upper bound for nutrients where available.

Table 1. Summary of Nutrient Constraints applied in the Linear Optimization Model

| ***Category*** | ***Nutrients*** | ***Unit*** | ***Lower Bound*** | ***Upper Bound*** |
|---|---|---|---|---|
| **Nutrients to encourage** | Protein | g | 50 | 175 |
| | Fiber | g | 28.5 | N/A |
| | Vitamin A | μg | 800 | 3000 |
| | Vitamin B12 | mg | 2.4 | N/A |

| *Category* | *Nutrients* | *Unit* | *Lower Bound* | *Upper Bound* |
|---|---|---|---|---|
| | Vitamin C | mg | 82.5 | 2000 |
| | Calcium | mg | 1100 | 2500 |
| | Magnesium | mg | 362.5 | N/A |
| | Iron | mg | 8 | 45 |
| | Potassium | mg | 3000 | N/A |
| **Nutrients to limit** | Sodium | mg | 500 | 2300 |
| | Added Sugar | g | N/A | 50 |
| | Saturated Fat | g | N/A | 22 |

#### 3.3.4.1.3 Consumption Constraints

Consumption constraints are critical in diet-related LO as they avoid extreme deviation from current consumption and unrealistic modelled diets. Without such constraints, the objective of LO can still be achieved but with impractical diets. For example, Macdiarmid et al. (2012) achieved a 90% reduction in GHGE against a 1990 UK baseline diet, but included only seven food items, specifically fortified whole grain breakfast cereal, with unrealistic large quantities.

A key consumption constraint in this study involves setting the lower bounds for food items with no change (excluding whole wheat grains) at 50% of Ontario average, because it is proven to be impractical for people to change more than 50% of their current DPs based on behavioral economic theory of loss aversion (Masino et al., 2023). Another important consumption constraint is the intake for dark green (broccoli and spinach) and orange (carrot and squash) vegetables. These vegetables are specifically highlighted within the vegetable category, even though the 2019 CFG does not specify recommended amounts for them. Thus, the items and recommended intakes are sourced from the 2007 CFG and the EAT-Lancet Diet (Willett et al., 2019) as the lower bounds for dark green and orange vegetables. All the consumption constraints with rationales are summarized in Table 2.

Table 2. Summary of Consumption Constraints applied in the Linear Optimization

| **Consumption Constraints** | **Reference for Rationale** |
|---|---|
| Amount of all the vegetables ≥ 239.71g | EAT-Lancet Diet (Willett et al., 2019) |
| Amount (broccoli + spinach) ≥ 79.9g | |
| Amount (carrot + squash) ≥79.9g | |
| Amount (other vegetables in the vegetable category) ≥ 79.9g | |
| Amount of potato ≤ 39.95g | |
| Amount of (almond + cashew + walnut) ≤ 20g | (Harvard Health, 2014) |
| Amount of canola oil = 22.6g | (Liu et al., 2017) |
| Amount of olive oil = 22.6g | |
| Amount of all beverages (coffee + tea + water) = 2000g | (Harvard Health, 2023) |

*3.3.4.2 NNFB*

As previously mentioned, the NNFB specifies food amounts based on age and gender. For this study, the food amounts from the NNFB for adults were recalculated using the population data from Statistics Canada (2024), resulting in a weighted average, which was then adjusted to 2000 kcal using nutrient data from the CNF. The NNFB includes a total of 61 food items (no beverages included), with specific quantities detailed in Table A - 3 in Appendix A. It is important to highlight that the NNFB provide food amounts that are "as purchased", which were used as inputs in the LCI. However, when evaluating the nutrition, the "as consumed" quantities are required, accounting for food losses or changes due to household food preparation and cooking. Conversion factors from Bowman et al. (2013), as referenced in the NNFB, were applied to convert "as purchased" amounts to "as consumed" amounts.

*3.3.4.3 LCI Database*

The LCA data for this study was developed for food specifically consumed in Ontario, Canada, based on ecoinvent© LCI in openLCA. The database includes food items modeled as 1 kg of consumed food, with system boundaries extending from farm to fork. This encompasses five key life cycle stages: production, processing, distribution, retail, and consumption. Transportation and food waste are integrated at each stage of the supply chain. Transportation data are derived from the origin of production, with distances calculated using Canadian trade data, covering both domestic and imported foods. Food waste estimates are sourced from USDA LAFA 2015 and

Bognar (2002). Storage is accounted for during processing, distribution, and retail stages, while cooking is included in the consumption stage.

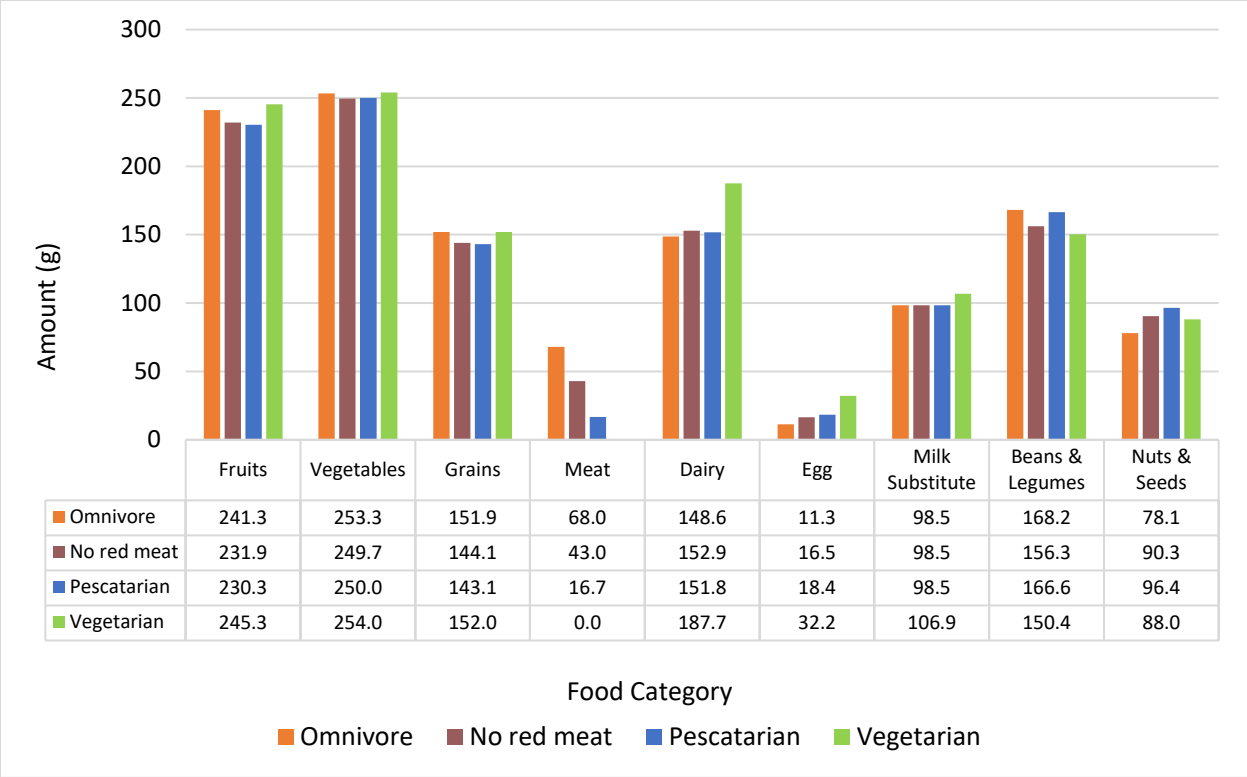
In the production stage, animal-based foods are modeled based on Canadian production data, utilizing either Canadian and U.S. LCA studies or ecoinvent_v38 processes. For example, salmon is modeled from (Pelletier et al., 2009), while pork is modeled using the Canadian process available in ecoinvent_v38. The database includes life cycle inventories (LCIs) for beef, salmon, chicken, and eggs, the latter sourced from Pelletier (2017). Canadian processes for pork, milk, cheese, and yogurt are selected from ecoinvent_v38. Plant-based foods are modeled using available ecoinvent_v38 processes, with production practices differentiated where significant differences exist, such as between greenhouse and field-grown foods. For instance, both field-grown and heated greenhouse tomatoes are considered, with proportions based on trade data. Since a publicly available LCA study exists for Canadian heated greenhouse tomatoes (Dias et al., 2016), its LCI has been incorporated into the database.

## 3.4 Results & Discussion

This chapter presents the results from the LO for the four optimized diets, nutritional assessment and LCA for the six DPs for Ontario: the four optimized diets, the Ontario average diet from 2015 CCHSN, and the NNFB. All the results in this study are based on 2000 kcal.

### 3.4.1 Amounts of Food Items in DPs

Figure 1 presents the findings for four optimized dietary scenarios: omnivore, vegetarian, pescatarian, and no red meat based on 2000 kcal (beverages and fats & oils excluded). Under the meat category, the omnivore diet includes 18.3g beef, 11.6g pork, 28.4g poultry, and 9.7g of fish & seafood, the pescatarian diet has 16.7g fish & seafood, and the no red meat diet has 28.4g poultry and 14.6g fish & seafood. For the categories of fats & oils and beverages, the same consumption constrains are applied across all the four optimized diets, with each diet including 45.2g of fats & oils and 2000g of beverages.




| | Fruits | Vegetables | Grains | Meat | Dairy | Egg | Milk Substitute | Beans & Legumes | Nuts & Seeds |
|---|---|---|---|---|---|---|---|---|---|
| Omnivore | 241.3 | 253.3 | 151.9 | 68.0 | 148.6 | 11.3 | 98.5 | 168.2 | 78.1 |
| No red meat | 231.9 | 249.7 | 144.1 | 43.0 | 152.9 | 16.5 | 98.5 | 156.3 | 90.3 |
| Pescatarian | 230.3 | 250.0 | 143.1 | 16.7 | 151.8 | 18.4 | 98.5 | 166.6 | 96.4 |
| Vegetarian | 245.3 | 254.0 | 152.0 | 0.0 | 187.7 | 32.2 | 106.9 | 150.4 | 88.0 |

Figure 1. Amounts in grams by Food Category in Four Optimized Diets

Figure 2 compares the four optimized diets with the Ontario average consumption and reveals significant shifts required to meet the 2019 CFG. Specifically, the optimized omnivore diet shows a substantial reduction in meat (68g, -62.0%) and dairy (148.6g, -44.5%), with a marked increase in beans & legumes (168.2g, +924.0%) and nuts & seeds (78.1g, +524.8%). Similar patterns are observed across the other optimized diets – vegetarian, pescatarian, and no red meat – though these diets eliminate certain categories due to their specific dietary restrictions. The observed trends, particularly the reduction in meat and increase in plant-based proteins, are consistent with findings from other diet-related LO studies in other countries aimed at improving environmental sustainability (Chaudhary & Krishna, 2019; Colombo et al., 2023; van Dooren et al., 2013; van Dooren & Aiking, 2015; Macdiarmid et al., 2012). All the four optimized diets also demonstrate the same increases in fats & oils (+84.5%) and beverages (+19.1%) from the consumption constraints, and eliminate the categories of snacks, sweets, and spices.

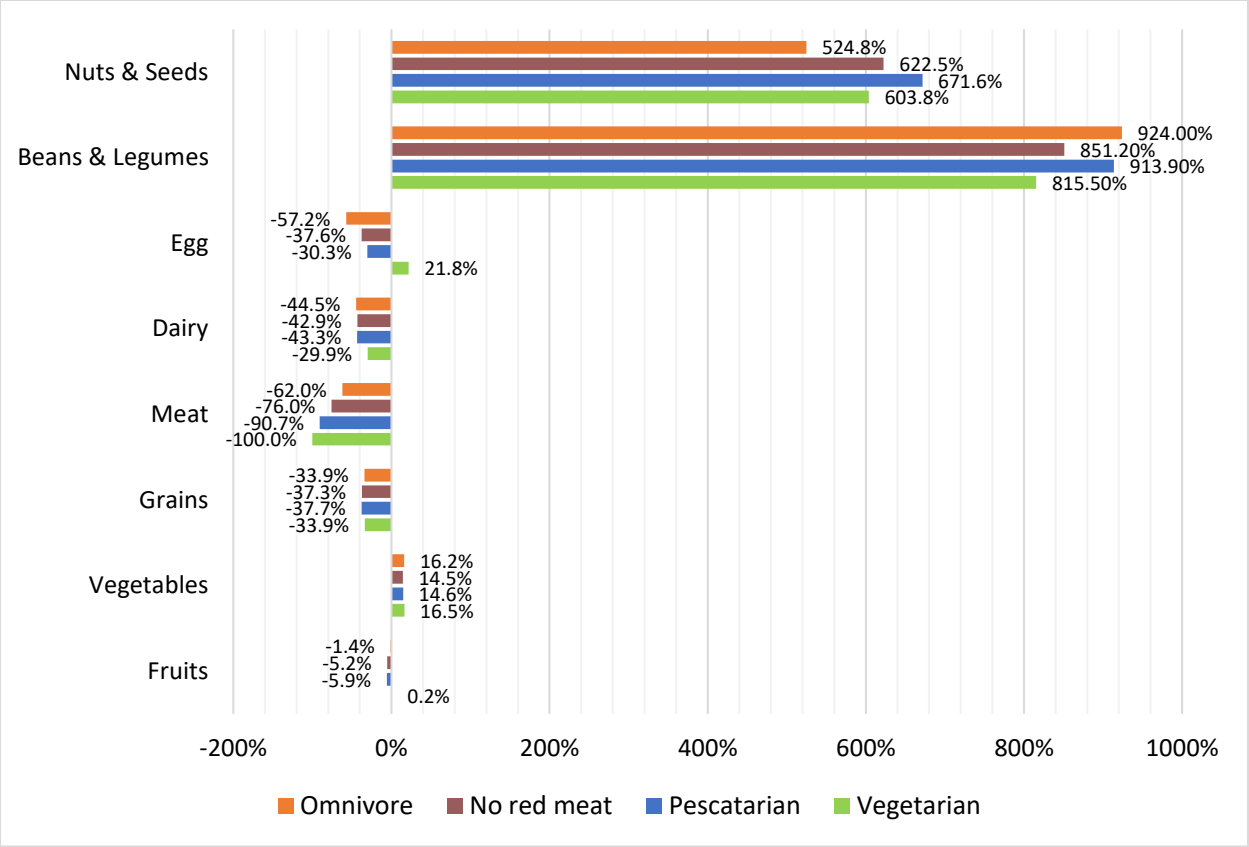



Figure 2. Percentage Difference in Food Categories of Four Optimized Diets Compared to the Ontario Average Consumption

Figure 3 compares the four optimized DPs with the NNFB. In this case, the four optimized diets feature more fruits (+62.0%) and fewer vegetables (-46.9%) on average. This discrepancy arises because the NNFB is based on the 2019 CFG, which provides only a general guideline that half of one's plate should consist of fruits and vegetables, while lacks detailed instructions on the exact quantities of fruits and vegetables to consume. Moreover, the optimized diets have significantly higher amounts of plant-based protein (+207.7% for beans & legumes, +363.0% for nuts & seeds) and fats & oils (+401.1%) on average than the NNFB. Interestingly, the optimized omnivore includes more meat (+29.5%) than the NNFB, primarily to meet essential nutritional requirements such as vitamin B12 and iron.

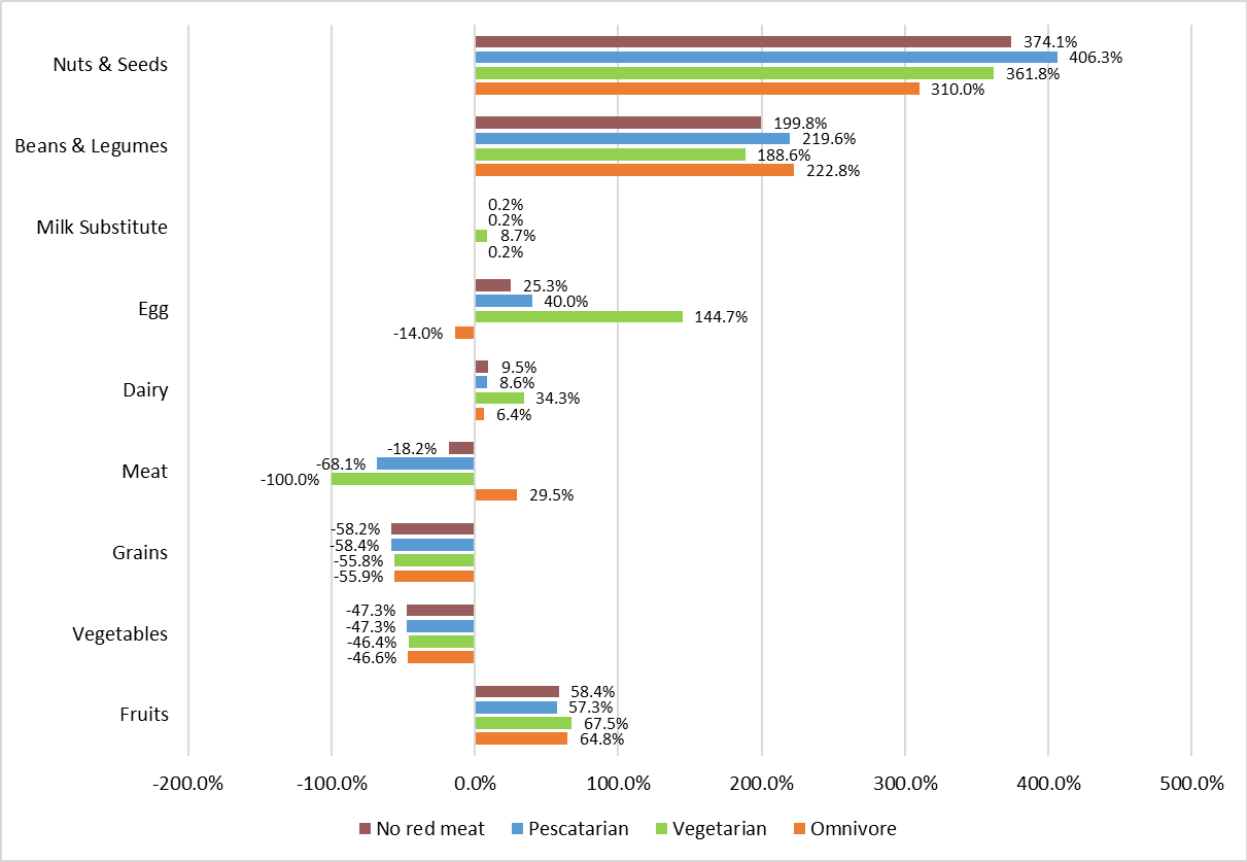



Figure 3. Percentage Difference in Food Categories of Four Optimized Diets Compared to the NNFB

### 3.4.2 NRF 9.3 score and Nutrition

For the six DPs, the NRF9.3 scores rank from highest to lowest as follows: omnivore (8.32) > no red meat (8.02) > vegetarian (7.94) > pescatarian (7.98) > NNFB (7.49) > Ontario average (5.29).

The nutritional assessment for the Ontario average diet from the 2015 CCHSN reveals an unbalanced consumption pattern. The Ontario average diet has significant overconsumption of protein, vitamin B12, saturated fat, and sodium, along with deficiencies in most micronutrients except for vitamin C. These imbalances mainly come from excessive consumption of meat, non-whole grain foods, and snack items as well as inadequate intake of fruits, vegetables, and whole grains. These findings align with previous research on Ontario food consumption (Prowse et al., 2022).

In contrast, the four optimized diets show excellent NRF9.3 score, reflecting the study's objective of maximizing nutrition through LO. One noteworthy finding is that all the four optimized diets only reach the lower bound for calcium intake. This is because many the calcium-rich food, such as dairy products, tend to have relatively high GWP, leading to their limited inclusion to compensate for the overall GWP. While plant-based foods can also provide calcium, their bioavailability is lower compared to dairy. This highlights that achieving sufficient calcium intake is possible but challenging, especially when prioritizing low GWP. This finding suggests a potential trade-off between nutritional adequacy and environmental impact.

For the NNFB, the NRF 9.3 score is 7.49, which is lower than those scores for the optimized DPs. Although this score appears high, there are deficiencies in nearly all beneficial nutrients except protein, fiber, and vitamin A. Calcium intake in particular only reached 51.2% of the DV. At the same time, the NNFB emphasizes food with low or no sodium and added sugar, resulting in good performance in these areas.

### 3.4.3 LCA Results

#### *3.4.3.1 Global Warming Potential of Optimized DPs compared to Ontario average and NNFB*

The Ontario average diet has the GWP of 6.5 kg $CO_2$ eq. The top three category contributors are meat (50.9%), dairy (13.0%) and vegetables (8.8%) and the top three item contributors are beef (31.3%), chicken (7.3%) and salmon (7.3%). The NNFB has the GWP of 3.2 kg $CO_2$ eq (-50.0% compared to the Ontario average). The GWP contribution for NNFB shows different patterns. The top three category contributors are vegetables (38.8%), meat (19.3%), and grains (13.0%) and the top three item contributors are lettuce (10.6%, due to its relatively large quantity), beef (7.8%) and salmon (5.4%).

The optimized omnivore diet has a GWP of 4.1 kg $CO_2$ eq (-36.1%), 3.2 kg $CO_2$ eq (-51.1%) for vegetarian, 3.2 kg $CO_2$ eq (-50.7%) for pescatarian, and 3.3 kg $CO_2$ eq (-48.7%) for no red meat, compared to the GWP of the Ontario average. The top three category contributors are meat (27.9%), dairy (14.7%), and vegetables (12.3%) for omnivore, dairy (21.8%), vegetables (16.2%) and fruits (15.0%) for vegetarian, dairy (20.2%), vegetables (15.6%) and fruits (13.8%) for pescatarian, and dairy (19.8%), vegetables (15.1%) and fruits (13.4%) for no red meat. Beef serves as the top item contributor for omnivore while cheese is the primary contributor for vegetarian, pescatarian, and no red meat. As commonly demonstrated in the literature (Poore &

Nemecek, 2018; Springmann et al., 2018), animal-sourced protein (meat and dairy) remains the hotspot for GWP, though their impact is significantly reduced in the optimized diets. In comparison, the contribution to GWP from plant-based protein (beans & legumes and nuts & seeds) is relatively modest, accounting for 12.1% in omnivore, 15.5% in vegetarian, 16.9% in pescatarian, and 15.4% in no red meat. Compared to the Ontario average, where plant-based proteins contribute to only 1% of GWP, the slight increase in GWP from the more inclusion of plant-based proteins in the optimized diets shows the environmental efficiency of these foods. The ranking of GWP per 2000 kcal from highest to lowest is: Ontario average > omnivore > no red meat > NNFB > pescatarian > vegetarian.

For comparison, Veeramani et al. (2016) developed nutritionally balanced, climate-friendly, and socially viable DPs based on the 2007 CFG using consumption data from the 2004 CCHS and found that omnivore diet could achieve a 34% reduction in GWP compared to the 2004 average omnivore consumption. In this study, a 36.1% reduction in GWP was achieved, reflecting a similar level of improvement. However, direct comparisons are not feasible due to differences in system boundaries and the database used in each analysis.

According to the planetary boundary for food systems set by the EAT-Lancet Commission (Willett et al., 2019), the GHGE should not exceed 625 kg $CO_2$ eq per person per year (Moberg et al., 2020). This translates to approximately 1.37 kg $CO_2$ eq per person per day for a 2000 kcal diet, assuming a global population of eight billion. In this study, the GWP for a 2000 kcal diet ranges from 3.16 to 4.13 kg $CO_2$ eq per person per day, which exceeds the planetary boundary. Therefore, while progress has been made, further substantial reductions in GHG emissions are necessary to align with sustainable food system targets. Meeting the planetary boundary will demand both individual dietary changes and systemic transformations within food production and consumption systems.

Applying the FU of NRF 9.3 score (Figure 4) allows for the comparison of the environmental impact of diets based on their nutritional quality. The ranking of GWP values per NRF 9.3 from highest to lowest is: Ontario average > omnivore > NNFB > no red meat > pescatarian > vegetarian. Figure 5 shows the comparison of GWP results using the FU of 2000 kcal vs. NRF 9.3 score. The NNFB presents a unique case, as its ranking shifts slightly when applying NRF 9.3 to GWP. While the NNFB has a relatively low GWP impact per 2000 kcal (the

fourth highest among the six DPs), its lower NRF9.3 score leads to a higher GWP per NRF 9.3, ranking it as the third highest.

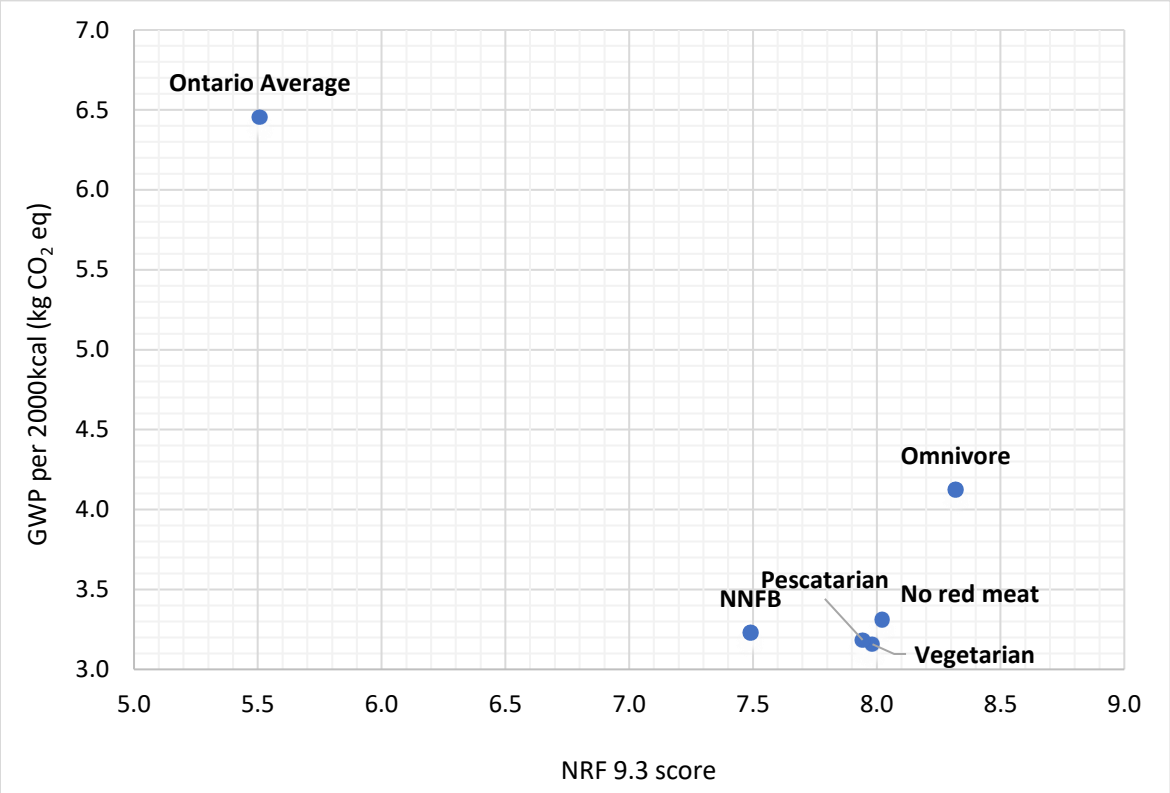



Figure 4. GWP per 2000 kcal vs. the NRF 9.3 score for the six DPs

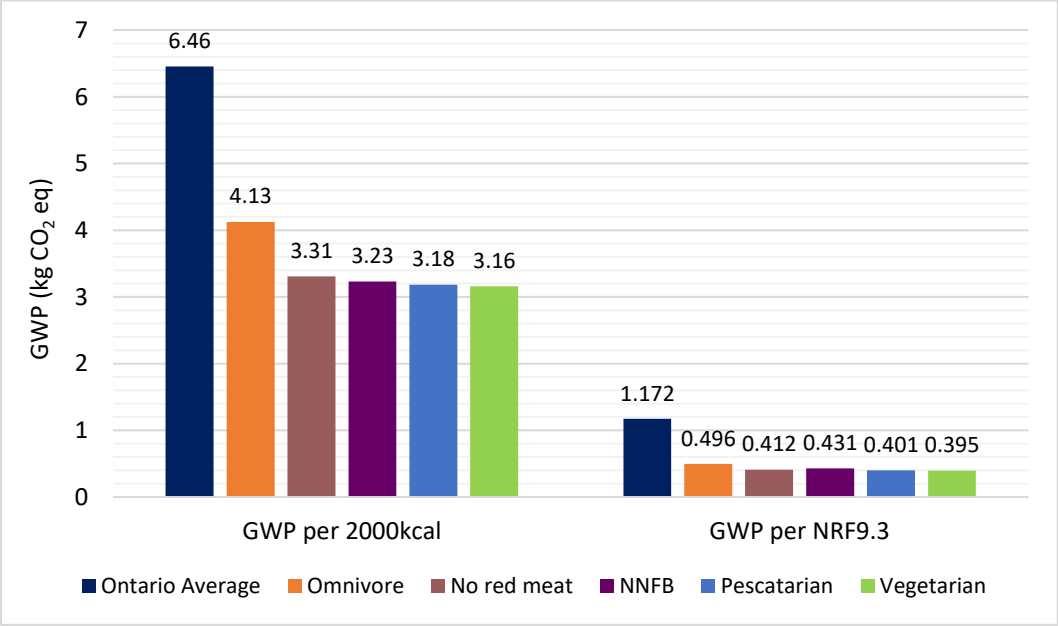



Figure 5. Comparison of GWP per 2000kcal vs. per NRF 9.3 score

*3.4.3.2 Other Impact Categories*

EU patterns are similar to those observed for GWP (Figure 6), with the NNFB as an exception. For EU per 2000 kcal, the Ontario average has the impact of 0.086 kg N eq, with the top three category contributors of meat (63.2%), dairy (10.0%), and fats & oils (7.4%) and top three item contributors of beef (40.5%), salmon (14.6%) and chicken (5.2%). Compared to the Ontario average, the EU impact is as follows: 0.057 kg N eq (-34.3%) for omnivore, 0.040 kg N eq (-54.2%) for vegetarian, 0.046 kg N eq (-46.4%) for pescatarian, 0.047 kg N eq (-45.9%) for no red meat, and 0.033 kg N eq (-62.1%) for the NNFB. In the four optimized diets, meat, dairy, fats & oils, and beverages remain the top category contributors and beef, salmon, vegetable oil, olive oil, and coffee contribute to EU the most. The NNFB, which does not include beverages, exhibits low EU impacts both per 2000 kcal and per NRF9.3 score. Its top three category contributors are meat, vegetables, and grains and the top three item contributors are salmon, beef, and milk.

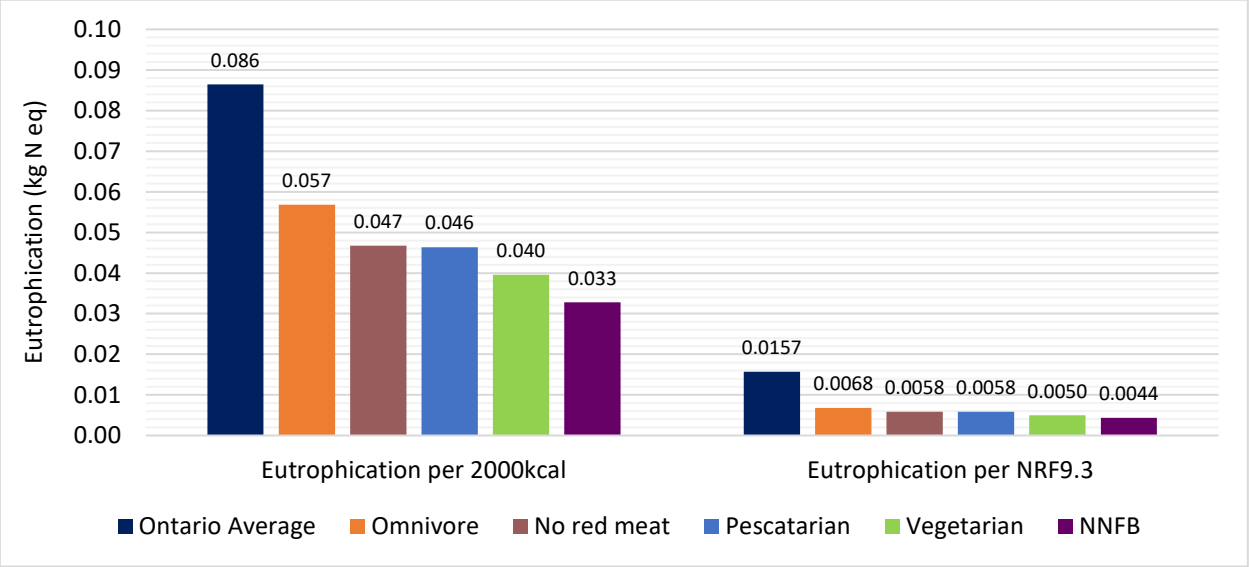



Figure 6. Comparison of EU per 2000kcal vs. per NRF 9.3 score

In terms of WF (Figure 7), the results differed significantly compared to other environmental impacts. Figure 7 shows the WF ($m^3$) and ranking for the six DPs. The four optimized DPs surprisingly have the highest WF, with the top three category contributors of nuts & seeds, fruits, and beverages and the top three item contributors being almonds, brewed tea, and grapes. The elevated water use in the four optimized DPs is primarily driven by the high consumption of almonds, which are known for their substantial WF (Fulton et al., 2019). In contrast, the Ontario average diet and the NNFB have relatively low WFs, with the top three

category contributors being fruits, grains, and vegetables. Due to the exclusion of beverages and the limited inclusion of items with high WFs, the NNFB shows the best performance for WF. These findings reveal the trade-offs among different environmental impacts. While the optimized DPs have relatively low GWP and EU impacts, they have a notably high WF.

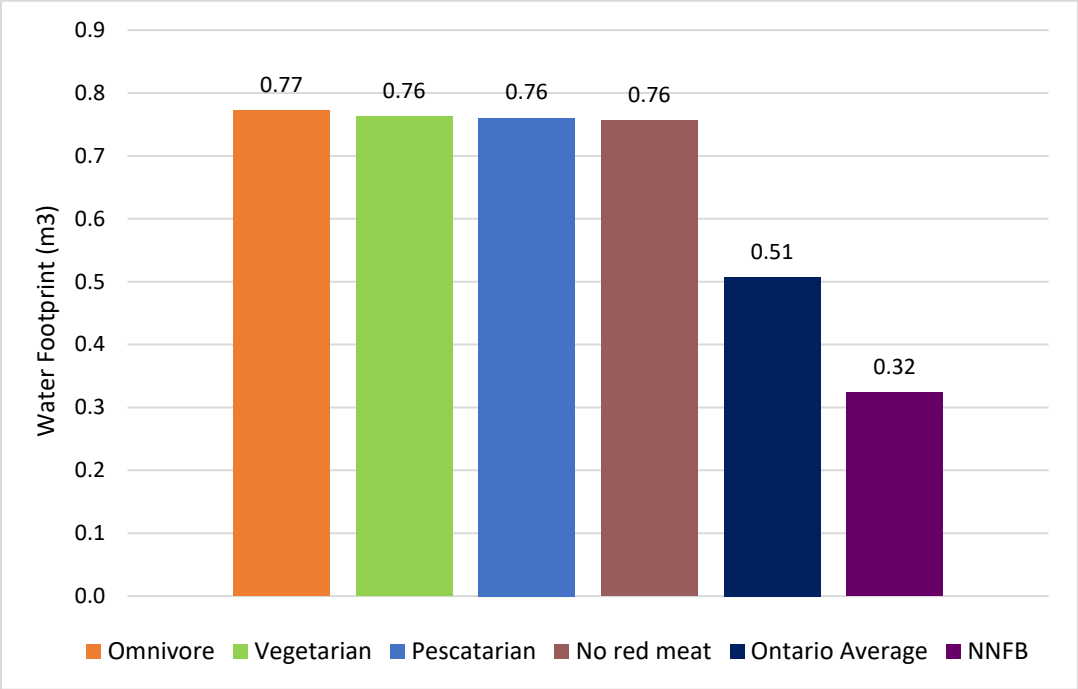



Figure 7. Water Footprint ($m^3$) for six DPs

### 3.4.4 Sensitivity Analysis

In LCA, sensitivity analysis assesses the robustness of results and sensitivity to uncertain factors (Wei et al., 2015), particularly for top contributors. In this study, the primary uncertainty lies in the GWP value for beef, due to inconsistencies in the literature. For instance, Aboagye et al. (2024) reports a GWP value of 32.80 kg $CO_2$ eq per kg of consumed beef, while the Ontarian LCI database used in this study provides a value of 55.65 kg $CO_2$ eq. To address this discrepancy, this study uses the average of these two values in the LO and LCA results.

Since only the Ontario average diet, the NNFB, and the optimized omnivore diet include beef, the GWP for these three DPs was affected. Table 3 illustrates how the total GWP of these DPs would change based on the different GWP values for beef. However, altering the GWP of beef would not affect the overall ranking of GWP among the six DPs.

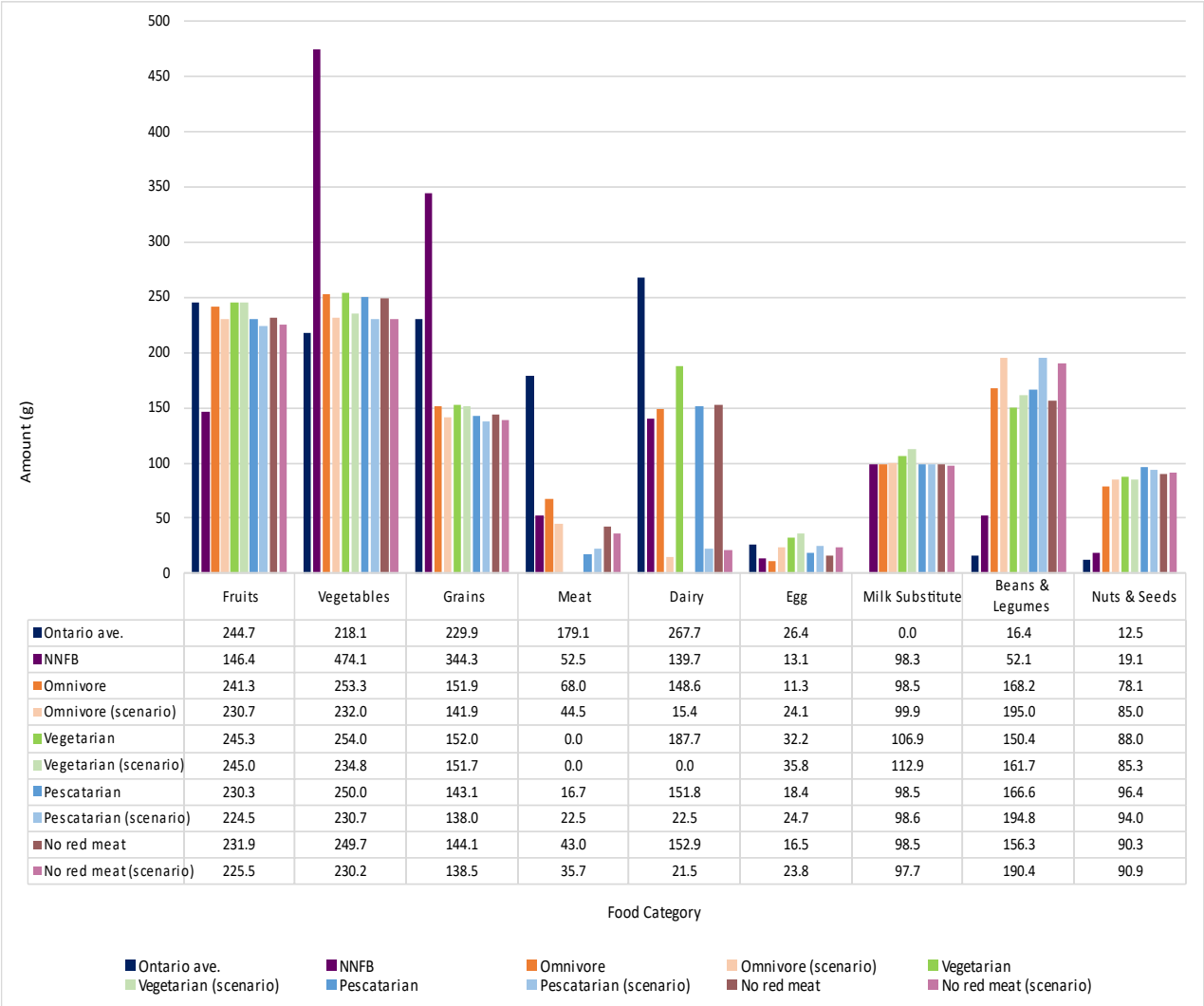
Table 3. Total GWP of DPs based on Different GWP Values for Beef

| | Total GWP of DP (kg $CO_2$ eq) | | |
|---|---|---|---|
| GWP value of Beef (kg $CO_2$ eq) | Ontario average | NNFB | Omnivore |
| 32.8 | 6.01 | 3.18 | 3.95 |
| 42.12 (Baseline) | 6.46 | 3.23 | 4.13 |
| 55.65 | 7.10 | 3.29 | 4.31 |

### 3.4.5 Scenario Analysis

Scenario analysis in LCA refers to the process of assessing potential impacts of different scenarios or alternative options for the same product or system (Pesonen et al., 2000). It allows for the evaluation of the environmental and social consequences of different choices. In this study, a key scenario to be examined is setting the consumption constraint (the lower bound of all food items) to 50% of the Ontario average consumption from the 2015 CCHSN. It would be interesting to test a consumption constraint at 25% of the Ontario average consumption as this could potentially reduce the total GWP, even if behaviorally it may be difficult to achieve.

Figure 8 illustrates the new quantities of food item in each category across four optimized diets after applying the new consumption constraint in LO. As expected, reducing the amounts of food high in GWP, such as meat and dairy, results in a decrease in the total GWP for all the four DPs, as shown in Figure 9. Notably, the omnivore diet shows a 14.1% reduction in GWP with the new consumption constraint while the other three optimized DPs have only slight reductions. The change in food amounts also impacts the NRF9.3 score (Figure 10), with up to a 4.2% reduction across the four diets, although all nutrients remain within the acceptable range.




| | Fruits | Vegetables | Grains | Meat | Dairy | Egg | Milk Substitute | Beans & Legumes | Nuts & Seeds |
|---|---|---|---|---|---|---|---|---|---|
| Ontario ave. | 244.7 | 218.1 | 229.9 | 179.1 | 267.7 | 26.4 | 0.0 | 16.4 | 12.5 |
| NNFB | 146.4 | 474.1 | 344.3 | 52.5 | 139.7 | 13.1 | 98.3 | 52.1 | 19.1 |
| Omnivore | 241.3 | 253.3 | 151.9 | 68.0 | 148.6 | 11.3 | 98.5 | 168.2 | 78.1 |
| Omnivore (scenario) | 230.7 | 232.0 | 141.9 | 44.5 | 15.4 | 24.1 | 99.9 | 195.0 | 85.0 |
| Vegetarian | 245.3 | 254.0 | 152.0 | 0.0 | 187.7 | 32.2 | 106.9 | 150.4 | 88.0 |
| Vegetarian (scenario) | 245.0 | 234.8 | 151.7 | 0.0 | 0.0 | 35.8 | 112.9 | 161.7 | 85.3 |
| Pescatarian | 230.3 | 250.0 | 143.1 | 16.7 | 151.8 | 18.4 | 98.5 | 166.6 | 96.4 |
| Pescatarian (scenario) | 224.5 | 230.7 | 138.0 | 22.5 | 22.5 | 24.7 | 98.6 | 194.8 | 94.0 |
| No red meat | 231.9 | 249.7 | 144.1 | 43.0 | 152.9 | 16.5 | 98.5 | 156.3 | 90.3 |
| No red meat (scenario) | 225.5 | 230.2 | 138.5 | 35.7 | 21.5 | 23.8 | 97.7 | 190.4 | 90.9 |

Figure 8. Food Amounts in grams by Food Category in all the DPs

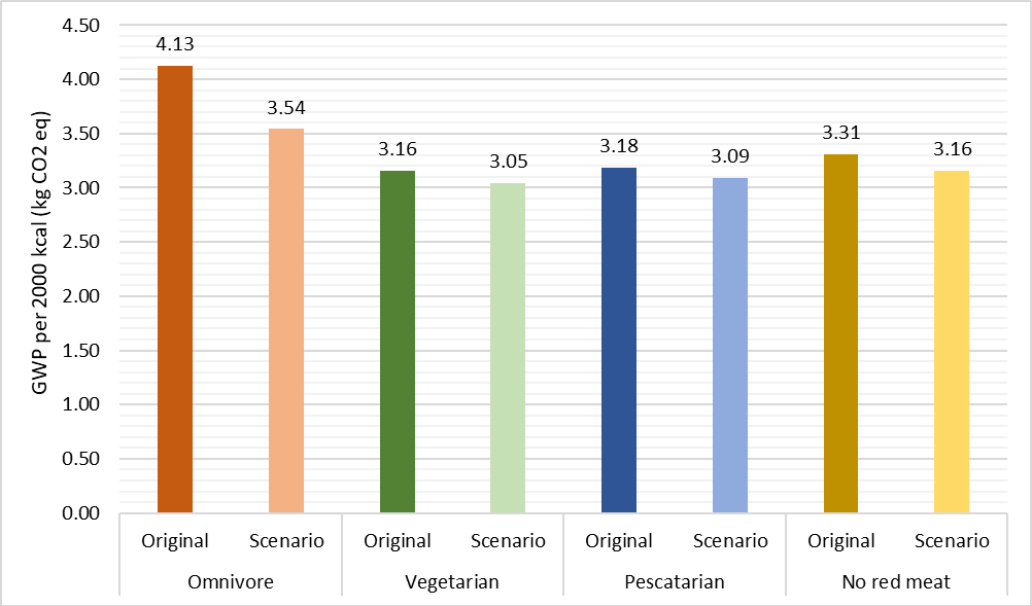



Figure 9. GWP per 2000 kcal: Comparison of Optimized DPs in Original vs. Scenario

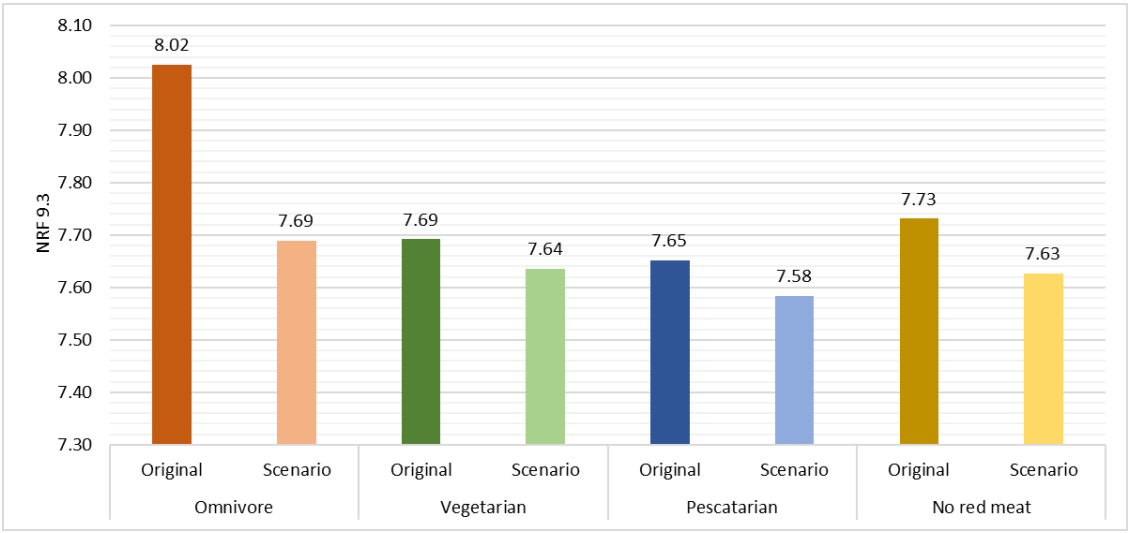



Figure 10. NRF 9.3: Comparison of Optimized DPs in Original vs. Scenario

Table 4 shows the summary of changes for scenario analysis compared to the original optimized DPs. For EU, the omnivore diet shows an 8.1% reduction, and the vegetarian diet has a 0.8% reduction. However, the pescatarian and no red meat diets experience an increase in EU due to the increased consumption of salmon. Regarding the WF, there is an up to 2% reduction across the four optimized diets.

Table 4. Scenario Analysis: Changes in GWP, NRF 9.3, EU, and WF Compared to Original Optimized DPs

| DPs | GWP | NRF 9.3 | EU | WF |
|---|---|---|---|---|
| Omnivore | -14.1% | -4.1% | -8.1% | -2% |
| Vegetarian | -3.5% | -0.7% | -0.8% | -1% |
| Pescatarian | -2.9% | -0.9% | 4.6% | -1% |
| No red meat | -4.6% | -1.3% | 4.3% | -1% |

In summary, lowering the consumption constraint from 50% to 25% would reduce the GWP, but this shift also leads to a slight reduction in nutritional quality and even increases in EU for some diets.

### 3.4.6 Strengths and Limitations

This study represents the first ever research to use LCA and LO for diet modelling in Canada, specifically targeting the province of Ontario. Incorporating both energy-based and nutrition-based FUs ensures a balanced assessment where environmental benefits do not come at the expense of nutritional adequacy. In addition, this study takes multiple environmental impacts into account, to fully understand the comprehensive impacts and the trade-offs associated with different DPs. By examining these various impacts, this research provides a holistic view of the environmental impacts, allowing for a more nuanced understanding of the sustainability of food choices. This comprehensive approach sets a precedent for future diet modelling and LCA for Canada and offers valuable insights for policymakers and stakeholders in the pursuit of sustainable dietary guidelines.

While this study focused on Ontario-specific DPs, it does not include direct comparisons with other countries due to methodological differences, such as varying FUs and system boundaries. It is important to note that environmental impacts of food products can vary significantly across studies depending on geographic differences and methods used, and there are substantial differences in food cultures and preferences among different countries (van Dooren, 2018). As a result, the results from a country-specific approach becomes evident as it allows for the development of dietary recommendations that are tailored to the unique environmental, cultural, and nutritional contexts of a particular country or region. Therefore, while comparing results across countries in absolute terms might be challenging and potentially misleading,

focusing on within-country assessments provides more relevant and actionable insights for national dietary guidelines and policy development.

This study also has several limitations. First of all, it relies on food item data from 2015 CCHSN, which may not represent the most comprehensive and updated DPs for Canadians, specifically Ontarians. As mentioned, the 2015 CCHSN performed 24-hour dietary recall for data collection. It is a widely used tool in nutritional research and dietary assessment due to its ease of administration and usefulness for obtaining snapshots of dietary habits. However, a major limitation of the 24-h dietary recall is recall bias, where respondents may misreport their food intake. Moreover, the 2015 CCHSN included only 119 food items, and this study only includes 69 items, while in reality, people consume a far greater variety of foods. This limited dataset may not fully capture the diversity of Ontarian diet. In addition, recent dietary shifts, particularly during the COVID-19 pandemic, have been reported (Janssen et al., 2021), indicating changes in eating habits that are not reflected in the 2015 data. The ongoing data collection for the 2024 CCHS could offer more valuable insights into recent dietary trends and patterns, enhancing the validity and reliability of future studies. Moreover, there has been surge of increase of new alternative protein foods in recent years (Kraak & Aschemann-Witzel, 2024), offering more sustainable options that are worth exploring and assessing. Also, the development of data for different regions in Canada are required to better understand regional dietary variations and their environmental impacts, which could further refine and contextualize the findings of this study.

In the realm of LO for diet modelling, the majority of existing literature focuses on minimizing deviations from the baseline diet (i.e., current average consumption) (Van Dooren, 2015). This approach tends to yield diets that are more acceptable since they involve smaller changes from the habitual DPs. In contrast, this study uses objective functions that maximize nutritional quality while minimizing GWP. Despite the application of various constraints to build reasonable diets, the optimized diets may still not be impractical for some individuals due to drastic changes in the consumption of several food categories or items. Furthermore, the LO approach in this study was designed with a dual focus on nutrition and environmental sustainability. However, affordability is another critical factor that influences people's food choices. Interestingly, evidence suggests that applying nutritional constraints could increase the costs while adding environmental constraints might help reduce the costs (Van Dooren et al., 2015). This indicates a complex

interaction between affordability, nutrition, and environmental impacts that need to be carefully balanced. Therefore, future research should take affordability into consideration, preferably as an additional objective of minimizing costs, to enhance the comprehensiveness in terms of truly sustainable diets and allow for a deeper exploration of the trade-offs between various factors. Integrating affordability into diet analysis in Canada can also contribute to future NNFB development, ensuring that dietary recommendations are not only health-promoting and environmentally responsible but also accessible and practical for all socioeconomic groups.

Besides, the LO model in this study addresses only the very general nutritional recommendation for adults by using the arithmetic mean of RDA for adult females and males. This generalized approach does not capture the specific nutritional needs of different age groups or genders. Future studies should aim to include age- and gender-specific nutrition recommendations to provide more tailored and accurate dietary optimizations. What's more, the nutritional constraints applied in this study did not consider the differences in nutrient bioavailability between plant-based and meat-based items, such as iron. Masino et al. (2023) applied an iron supply of 1.8 times the RDA for plant-based diets to account for the lower bioavailability of non-heme iron compared to heme iron in meat-based diets. This consideration is important for ensuring that nutrient needs are met effectively, especially in diets that rely heavily on plant-based foods. Future research should also integrate bioavailability factors into the optimization model to enhance the accuracy and practicality of dietary recommendations.

In terms of LCA, the environmental impacts for the NNFB would be an underestimation because it includes a significant amount of frozen or canned items, which are chosen for their affordability. The Canadian food database used in this study only accounts for fresh items, so the environmental impacts associated with the freezing or canning processes are not considered. This omission leads to an underestimation of the true environmental impacts for the NNFB.

This study is limited by its focus on Ontario due to lack of data for other regions in Canada. The environmental impacts of food or DPs can vary significantly across different provinces in Canada due to variation in food production practices such as different electricity grids and transportation distances, and local dietary habits. Consequently, developing a more extensive database for foods in other provinces and Canada as a whole is essential. Also, the LCA data used in this study only include the conventional products. Given the increasing production and

consumption of organic foods in Canada (Shahbandeh, 2024), it is also necessary to develop LCA data for organic foods. Organic foods have been proven to have lower GWP and EU (Hashemi et al., 2024). Considering organic foods in diet analysis could further reduce the GWP. Besides all the impact categories applied in this LCA, this study originally also wanted to capture the energy use in each life cycle of food using the Cumulative Energy Demand impact method. However, this was not achievable because it counts the caloric energy content of the food itself along with the energy used in production, transportation, cooking, etc. This conflation makes it challenging to distinguish the actual energy used in the food system from the nutritional energy provided by the food, leading to potential inaccuracies in accessing the environmental impacts.

## 3.5 Conclusion

This study developed optimized DPs based on the 2019 CFG using LO and evaluated their environmental impacts using LCA. It also compared these optimized diets with the average Ontario consumption from the 2015 CCHSN and the NNFB. The findings present the potential for significantly reducing GWP while maintaining nutritional adequacy for adults in Ontario, Canada. However, this study also showed the trade-offs between nutritional goals and environmental impacts—such as the challenge of meeting adequate calcium intake when minimizing GWP—as well as trade-offs among different environmental impacts, evidenced by the increased WF resulting from the higher consumption of water-intensive foods.

The implications of this research extend to future development of the Canada's Food Guide and similar dietary guidelines, spotlighting the importance of integrating environmental sustainability into nutritional advice. Policymakers should consider the broader environmental impacts of food choices, beyond GWP, to promote truly sustainable eating patterns. Furthermore, this study lays a foundation for developing dietary recommendations that are feasible, nutritionally adequate, and environmentally responsible.

Future research should address the limitations identified in this study, such as the reliance on 2015 CCHSN, which may not fully capture latest dietary trends. Additionally, further studies could explore the environmental impacts of DPs with more region-specific data into dietary assessments. By continuing to refine the methodologies and data used in such assessments, policy can be better informed, and consumers can be guided toward healthier and more sustainable food choices.

To further enhance sustainability, it is essential to complement optimized DPs with improvements in food production practices, such as advancing sustainable agriculture and reducing food loss and waste throughout the supply chain. Policy support, including taxes on unhealthy foods and subsidies for healthier options, along with investments in sustainable food technologies, can drive the adoption of sustainable practices.

In conclusion, this study provides a roadmap for future Canada's Food Guide and related policies that not only promote nutritional health but also protect the environment. By addressing the identified trade-offs and continuously improving the understanding of the complex interactions between diet and sustainability, it is possible to work toward a food system that benefits both people and the planet.

# Chapter 4 Conclusions and Recommendations

## 4.1 Conclusion

This study aimed to develop optimized DPs based on the 2019 CFG using LO and evaluate their environmental impacts using LCA. The study also compared these optimized diets with the average Ontario consumption pattern from the 2015 CCHSN and the NNFB. This research provides valuable insights into the trade-offs between nutritional adequacy and environmental sustainability as well as among different environmental impacts.

The findings from this study demonstrate that it is indeed possible to optimize DPs to significantly reduce environmental impacts, particularly in terms of GWP. All four optimized DPs showed substantial reductions in GWP compared to the Ontario average consumption, with reductions ranging from 36% to over 50%. These reductions are particularly critical given the growing global emphasis on reducing carbon emissions and combating climate change. The optimized diets, however, also revealed trade-offs, particularly increased WFs. This indicates that while diets can be optimized for lower GWP, it is equally important to consider other environmental impacts such as water use, which is becoming an increasingly critical issue in the context of global water scarcity.

Nutritionally, the optimized diets maintained a high level of quality, as indicated by their NRF 9.3 scores, which ranged from 7.94 to 8.32. These scores reflect the success of the LO approach in maximizing nutritional adequacy. However, this study also uncovered challenges in balancing nutritional goals with environmental sustainability. For instance, while the optimized diets achieved their primary objective of reducing GWP, they struggled to meet the recommended levels of certain nutrients, particularly calcium. This was largely due to the reduced inclusion of dairy products, which, although rich in calcium, are associated with higher GWP values. This finding highlights the complexity of designing diets that simultaneously optimize for both nutritional adequacy and environmental sustainability, especially when certain nutrients are more readily available in foods that have a higher environmental impact.

The NNFB, which serves as a benchmark for affordability and nutritional adequacy in Canada, presented an interesting case. Although it has a relatively low GWP compared to the Ontario average diet, its nutritional profile was less balanced, with significant deficiencies in key nutrients such as calcium, iron, and magnesium. The NNFB's focus on affordability and

accessibility likely contributes to its lower environmental impact, but this comes at the cost of a less satisfied nutritional intakes.

These findings have significant implications for future Canada's Food Guide and NNFB. This study highlights the importance of integrating environmental considerations into dietary recommendations to promote both nutritional health and sustainability. Policymakers, nutritionists and dietitians should consider the broader environmental impacts of food choices, beyond just GWP, to encourage truly sustainable eating patterns. Specifically, future versions of the CFG as well as guidance from nutritionists and dietitians, could play a pivotal role in raising public awareness of the environmental impacts of various food choices. Policymakers and health professionals should consider encouraging a shift towards more plant-based proteins while reducing the consumption of animal-based proteins, particularly red meat, as red meat has been widely proven to have negative health and environmental impacts. Although precise guidelines on environmentally sustainable food quantities may not be feasible, providing transparent information on the relative impacts of different foods can help consumers balance their personal preferences with sustainability goals. Additionally, highlighting the trade-offs between various environmental impacts—such as the higher water use of certain plant-based foods or the carbon footprint of imported items—will ensure that dietary recommendations are holistic and avoid inadvertently causing harm in one area while mitigating another.

Moreover, this study makes a substantial contribution to the field of sustainability management by demonstrating how dietary choices can be optimized to balance environmental sustainability with nutrition. The methodologies employed—particularly the integration of LO and LCA—offer a robust framework for designing and evaluating environmental impacts of DPs. The methodologies employed in this study, particularly the use of two FUs (energy-based and nutrition-based), offer a robust framework for assessing the comprehensive impacts of DPs. However, there is a need for more up-to-date and region-specific data to further refine this assessment.

In conclusion, this research presents the potential to develop DPs that are both nutritionally adequate and environmentally sustainable. By addressing the trade-offs between different environmental impacts and ensuring that dietary recommendations are grounded in the latest data, future updates to the Canada Food Guide and similar guidelines can better promote nutritional health and sustainability in tandem. This study's contribution to sustainability management lies in

its demonstration of how environmental and nutritional goals can be integrated into the management of food systems, paving the way for more sustainable food choices and policies.

## 4.2 Recommendations

While this study primarily focuses on optimizing DPs to reduce environmental impacts while maintaining nutritional adequacy, it is essential to recognize that changes in dietary consumption alone may not be sufficient to achieve the broader sustainability goals. To further mitigate the environmental impacts associated with food systems, improvements in food production practices must also be prioritized. These improvements can play a crucial role in complementing sustainable DPs and enhancing overall environmental outcomes.

Abe-Inge et al. (2024) showed excessive supply of animal products and added sugar, alongside an insufficient supply of plant-based proteins, vegetables, and healthy oils in Canada. Therefore, adjusting the food supply is also critical in improving sustainability as they directly impact consumers' food choices. In addition, advancements in sustainable agricultural practices and innovations in food technology can play a pivotal role in reducing the environmental impact of food production. Improving cattle production processes and adopting energy-efficient techniques in plant-based systems can significantly reduce environmental impacts (Aidoo et al., 2023).

Besides, reducing food loss and waste throughout the supply chain is critical. A significant portion of food is lost or wasted before it even reaches the consumer (FAO, 2013). Strategies to reduce food loss at the production, processing, and distribution stages—such as improving storage facilities, refining transportation logistics, and implementing better food handling practices—can substantially decrease the overall environmental impacts. Moreover, educating consumers on food waste reduction and better food management practices at the household level can further complement these efforts. Veeramani et al. (2016) demonstrated that reduce food waste in Ontario could lead to further decrease in GWP. Hence, addressing food loss and waste at both the systematic and individual levels can contribute to more sustainable food systems.

Policy support and incentives are also vital for driving the adoption of sustainable practices across the food system. Taxation of unhealthy foods such as the sugar sweetened beverage tax and subsidizing the cost of healthy foods have the great potential of encouraging health food options

(Kalamov, 2020; Sacks et al., 2021). Also, investments and financial support in sustainable food production as well as development of new sustainable food also contribute to a reduction in the environmental impacts associated with food production.

In conclusion, while optimizing DPs is a critical step toward sustainability, it must be complemented by improvements in food production practices, waste reduction, and policy support to achieve a truly sustainable food system. These recommendations provide a comprehensive approach that can help align food systems with environmental goals while ensuring nutritional adequacies for all.

# References


Abe-Inge, V., Kwofie, E. M., Kubow, S., Orsat, V., & Ulimwengu, J. M. (2024). Uncovering the gap: Assessing the compliance of the canadian food availability with dietary recommendations and its impact on the environment. *Global Food Security*, *40*, 100736. https://doi.org/10.1016/j.gfs.2023.100736

Arrieta, E. M., & Gonzalez, A. Z. (2018). Impact of current, National Dietary Guidelines and alternative diets on greenhouse gas emissions in Argentina. *Food Policy*, *79*, 58–66. https://doi.org/10.1016/j.foodpol.2018.05.003

Arsenault, N., Tyedmers, P., & Fredeen, A. (2009). Comparing the environmental impacts of pasture-based and confinement-based dairy systems in Nova Scotia (Canada) using life cycle assessment. International Journal of Agricultural Sustainability, 7(1), 19–41. https://doi.org/10.3763/ijas.2009.0356

Arsenault, N., Tyedmers, P., & Fredeen, A. H. (2009). Comparing the environmental impacts of pasture-based and confinement-based dairy systems in Nova Scotia (Canada) using life cycle assessment. *International Journal of Agricultural Sustainability*, *7*(1), 19–41. https://doi.org/10.3763/ijas.2009.0356

Auclair, O., & Burgos, S. A. (2021). Carbon footprint of Canadian self-selected diets: Comparing intake of foods, nutrients, and diet quality between low- and high-greenhouse gas emission diets. *Journal of Cleaner Production*, 128245. https://doi.org/10.1016/j.jclepro.2021.128245

Auclair, O., & Burgos, S. A. (2021). Protein consumption in Canadian habitual diets: usual intake, inadequacy, and the contribution of animal- and plant-based foods to nutrient intakes. *Applied Physiology, Nutrition, and Metabolism*, *46*(5), 501–510. https://doi.org/10.1139/apnm-2020-0760

Auestad, N., & Fulgoni, V. L., 3rd (2015). What current literature tells us about sustainable diets: emerging research linking dietary patterns, environmental sustainability, and economics. *Advances in nutrition (Bethesda, Md.)*, *6*(1), 19–36. https://doi.org/10.3945/an.114.005694

Bailey R. L. (2021). Overview of dietary assessment methods for measuring intakes of foods, beverages, and dietary supplements in research studies. *Current opinion in biotechnology*, *70*, 91–96. https://doi.org/10.1016/j.copbio.2021.02.007

Bamber, N., Johnson, R. F., Laage, E., Dias, G., Tyedmers, P., & Pelletier, N. (2022). Life cycle inventory and emissions modelling in organic field crop LCA studies: review and recommendations. *Resources Conservation and Recycling*, *185*, 106465. https://doi.org/10.1016/j.resconrec.2022.106465

Barnsley, J. E., Chandrakumar, C., Fischer, C. G., Eme, P. E., Bourke, B., Smith, N., Dave, L. A., McNabb, W. C., Clark, H. H., Frame, D. J., Lynch, J., & Roche, J. R. (2021). Lifetime Climate Impacts of Diet Transitions: A Novel Climate Change Accounting Perspective. *Sustainability*, *13*(10), 5568. https://doi.org/10.3390/su13105568

Baroni, L., Cenci, L., Tettamanti, M., & Berati, M. (2007). Evaluating the environmental impact of various dietary patterns combined with different food production systems. *European Journal of Clinical Nutrition*, *61*(2), 279–286. https://doi.org/10.1038/sj.ejcn.1602522

Barr, S. I. (2019). Is the 2019 Canada's Food Guide Snapshot nutritionally adequate? *Applied Physiology, Nutrition, and Metabolism*, *44*(12), 1387–1390. https://doi.org/10.1139/apnm-2019-0432

Batlle-Bayer, L., Aldaco, R., Bala, A., & Fullana-i-Palmer, P. (2020). Toward sustainable dietary patterns under a water–energy–food nexus life cycle thinking approach. *Current Opinion in Environmental Science & Health*, *13*, 61–67. https://doi.org/10.1016/j.coesh.2019.11.001

Batlle-Bayer, L., Bala, A., García-Herrero, I., Lemaire, E., Song, G., Aldaco, R., & Fullana-i-Palmer, P. (2019). The Spanish Dietary Guidelines: A potential tool to reduce greenhouse gas emissions of current dietary patterns. *Journal of Cleaner Production*, *213*, 588–598. https://doi.org/10.1016/j.jclepro.2018.12.215

Beal, T., Ortenzi, F., & Fanzo, J. (2023). Estimated micronutrient shortfalls of the EAT–Lancet planetary health diet. *The Lancet Planetary Health*, *7*(3), e233–e237. https://doi.org/10.1016/s2542-5196(23)00006-2

Beauchemin, K. A., Janzen, H. H., Little, S. M., McAllister, T. A., & McGinn, S. M. (2010). Life cycle assessment of greenhouse gas emissions from beef production in western Canada: A case study. *Agricultural Systems*, *103*(6), 371–379. https://doi.org/10.1016/j.agsy.2010.03.008

Behrens, P., Jong, J. C. K., Bosker, T., Rodrigues, J. D., De Koning, A., & Tukker, A. (2017). Evaluating the environmental impacts of dietary recommendations. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(51), 13412–13417. https://doi.org/10.1073/pnas.1711889114

Bellamy, A. S., Furness, E., Mills, S., Clear, A. K., Finnigan, S. M., Meador, E., Milne, A. E., & Sharp, R. T. (2023). Promoting dietary changes for achieving health and sustainability targets. *Frontiers in Sustainable Food Systems*, *7*. https://doi.org/10.3389/fsufs.2023.1160627

Beretta, C., Stoessel, F., Baier, U., & Hellweg, S. (2013). Quantifying food losses and the potential for reduction in Switzerland. *Waste Management*, *33*(3), 764–773. https://doi.org/10.1016/j.wasman.2012.11.007

Berners-Lee, M., Hoolohan, C., Cammack, H., & Hewitt, C. N. (2012). The relative greenhouse gas impacts of realistic dietary choices. *Energy Policy*, *43*, 184–190. https://doi.org/10.1016/j.enpol.2011.12.054

Bingham, S. A. (1991). Limitations of the Various Methods for Collecting Dietary Intake Data. *Annals of Nutrition and Metabolism*, *35*(3), 117–127. https://doi.org/10.1159/000177635

Brassard, D., & Chevalier, S. (2023). Relationship between Adherence to the 2019 Canada's Food Guide Recommendations on Healthy Food Choices and Nutrient Intakes in Older Adults. *The Journal of Nutrition*, *153*(9), 2699–2708. https://doi.org/10.1016/j.tjnut.2023.07.005

Brassard, D., Manikpurage, H. D., Thériault, S., Arsenault, B. J., & Lamarche, B. (2022). Greater adherence to the 2019 Canada's Food Guide recommendations on healthy food choices reduces the risk of cardiovascular disease in adults: a prospective analysis of UK Biobank data. *The American journal of clinical nutrition*, *116*(6), 1748–1758. https://doi.org/10.1093/ajcn/nqac256

Brassard, D., Manikpurage, H. D., Thériault, S., Arsenault, B. J., & Lamarche, B. (2022). Greater adherence to the 2019 Canada's Food Guide recommendations on healthy food choices reduces the risk of cardiovascular disease in adults: a prospective analysis of UK Biobank data. *The American Journal of Clinical Nutrition*, *116*(6), 1748–1758. https://doi.org/10.1093/ajcn/nqac256

Brassard, D., Munene, L. E., St Pierre, S., Guenther, P. M., Kirkpatrick, S. I., Slater, J., Lemieux, S., Jessri, M., Haines, J., Prowse, R., Olstad, D. L., Garriguet, D., Vena, J. E., Vatanparast, H., L'Abbé, M. R., & Lamarche, B. (2022). Development of the Healthy Eating Food Index (HEFI)-2019 measuring adherence to Canada's Food Guide 2019 recommendations on healthy food choices. *Applied Physiology, Nutrition, and Metabolism*, *47*(5), 595–610. https://doi.org/10.1139/apnm-2021-0415

Bruins, M. J., & Létinois, U. (2021). Adequate Vitamin D Intake Cannot Be Achieved within Carbon Emission Limits Unless Food Is Fortified: A Simulation Study. *Nutrients*, *13*(2), 592. https://doi.org/10.3390/nu13020592

Cambeses-Franco, C., Feijoó, G., & González-García, S. (2022). Co-benefits of the EAT-Lancet diet for environmental protection in the framework of the Spanish dietary pattern. *Science of the Total Environment*, *836*, 155683. https://doi.org/10.1016/j.scitotenv.2022.155683

Castañé, S., & Antón, A. (2017). Assessment of the nutritional quality and environmental impact of two food diets: A Mediterranean and a vegan diet. *Journal of Cleaner Production*, *167*, 929–937. https://doi.org/10.1016/j.jclepro.2017.04.121

Chapa, J., Farkas, B., Bailey, R. L., & Huang, J.-Y. (2020). Evaluation of environmental performance of dietary patterns in the United States considering food nutrition and satiety. *Science of The Total Environment*, *722*, 137672. https://doi.org/10.1016/j.scitotenv.2020.137672

Chaudhary, A., & Krishna, V. (2019). Country-Specific Sustainable Diets using optimization algorithm. *Environmental Science & Technology*, *53*(13), 7694–7703. https://doi.org/10.1021/acs.est.8b06923

Chaudhary, A., & Krishna, V. (2019). Country-Specific Sustainable Diets using optimization algorithm. Environmental Science & Technology, 53(13), 7694–7703. https://doi.org/10.1021/acs.est.8b06923

Chauhan, C., Dhir, A., Akram, M. U., & Salo, J. (2021). Food loss and waste in food supply chains. A systematic literature review and framework development approach. *Journal of Cleaner Production*, *295*, 126438. https://doi.org/10.1016/j.jclepro.2021.126438

Cleghorn, C., Nghiem, N., & Mhurchú, C. N. (2022). Assessing the health and environmental benefits of a New Zealand diet optimised for health and climate protection. *Sustainability*, *14*(21), 13900. https://doi.org/10.3390/su142113900

Coffey, A., Lillywhite, R., & Oyebode, O. (2022). P24 Meat vs meat alternatives: which is better for the environment and health? A nutritional and environmental analysis of animal-based products compared with their plant-based alternatives. *SSM Annual Scientific Meeting*. https://doi.org/10.1136/jech-2022-ssmabstracts.121

Colizzi, C., Harbers, M. C., Vellinga, R. E., Verschuren, W., Boer, J. M. A., Biesbroek, S., Temme, E. H. M., & Van Der Schouw, Y. T. (2023). Adherence to the EAT-Lancet Healthy reference Diet in relation to risk of cardiovascular events and environmental impact: results from the EPIC-NL cohort. *Journal of the American Heart Association*, *12*(8). https://doi.org/10.1161/jaha.122.026318

Colombo, P. E., Elinder, L. S., Lindroos, A. K., & Parlesak, A. (2021). Designing nutritionally adequate and Climate-Friendly diets for omnivorous, pescatarian, vegetarian and vegan adolescents in Sweden using linear optimization. *Nutrients*, *13*(8), 2507. https://doi.org/10.3390/nu13082507

Colombo, P. E., Elinder, L. S., Lindroos, A. K., & Parlesak, A. (2021). Designing nutritionally adequate and Climate-Friendly diets for omnivorous, pescatarian, vegetarian and vegan adolescents in Sweden using linear optimization. *Nutrients*, *13*(8), 2507. https://doi.org/10.3390/nu13082507

Colombo, P. E., Elinder, L. S., Lindroos, A. K., & Parlesak, A. (2021). Designing nutritionally adequate and Climate-Friendly diets for omnivorous, pescatarian, vegetarian and vegan adolescents in Sweden using linear optimization. Nutrients, 13(8), 2507. https://doi.org/10.3390/nu13082507

Colombo, P. E., Elinder, L. S., Nykänen, E. A., Patterson, E., Lindroos, A. K., & Parlesak, A. (2023). Developing a novel optimisation approach for keeping heterogeneous diets

healthy and within planetary boundaries for climate change. European Journal of Clinical Nutrition. https://doi.org/10.1038/s41430-023-01368-7

Corkum, A., MSc, Vanderlee, L., PhD, White, C. M., MSc, & Hammond, D., PhD (2022). Awareness of Canada's Food Guide Among Canadian Youth. *Canadian journal of dietetic practice and research: a publication of Dietitians of Canada = Revue canadienne de la pratique et de la recherche en dietetique : une publication des Dietetistes du Canada*, 1–5. Advance online publication. https://doi.org/10.3148/cjdpr-2022-019

Corkum, A., Vanderlee, L., White, C. M., & Hammond, D. (2023). Awareness of Canada's food guide among Canadian youth. *Canadian Journal of Dietetic Practice and Research*, *84*(1), 49–53. https://doi.org/10.3148/cjdpr-2022-019

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., & Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, *2*(3), 198–209. https://doi.org/10.1038/s43016-021-00225-9

Cucurachi, S., Scherer, L. D., Guinée, J. B., & Tukker, A. (2019). Life Cycle Assessment of Food Systems. *One Earth*, *1*(3), 292–297. https://doi.org/10.1016/j.oneear.2019.10.014

Curran, M. A. (2014). Strengths and Limitations of Life Cycle Assessment. In *Springer eBooks* (pp. 189–206). Springer Nature. https://doi.org/10.1007/978-94-017-8697-3_6

Daniel, C. R., Cross, A. J., Koebnick, C., & Sinha, R. (2011). Trends in meat consumption in the USA. *Public Health Nutrition*, *14*(04), 575–583. https://doi.org/10.1017/S1368980010002077

Dantzig, G. B., & Thapa, M. N. (2013). Linear Programming 1: Introduction. Springer.

Darmon, N., Vieux, F., Maillot, M., Volatier, J., & Martin, A. (2009). Nutrient profiles discriminate between foods according to their contribution to nutritionally adequate diets: a validation study using linear programming and the SAIN,LIM system. *The American Journal of Clinical Nutrition*, *89*(4), 1227–1236. https://doi.org/10.3945/ajcn.2008.26465

De Pee, S., Ridwan, H., Jalal, F., Kim, B. F., Semba, R. D., Deptford, A., Fanzo, J., Ramsing, R., Nachman, K. E., McKenzie, S., & Bloem, M. W. (2021). Balancing a sustained pursuit of nutrition, health, affordability and climate goals: exploring the case of Indonesia. *The*

*American Journal of Clinical Nutrition*, *114*(5), 1686–1697. https://doi.org/10.1093/ajcn/nqab258

Dias, G., Ayer, N. W., Khosla, S., Van Acker, R. C., Young, S. L., Whitney, S., & Hendricks, P. (2016). Life cycle perspectives on the sustainability of Ontario greenhouse tomato production: Benchmarking and improvement opportunities. *Journal of Cleaner Production*, *140*, 831–839. https://doi.org/10.1016/j.jclepro.2016.06.039

Dietary Guidelines Advisory Committee. (2015). Scientific report of the 2015 Dietary Guidelines Advisory Committee: advisory report to the Secretary of Health and Human Services and the Secretary of Agriculture. *Agricultural Research Service*, 2019-09.

Donati, M., Menozzi, D., Zighetti, C., Rosi, A., Zinetti, A., & Scazzina, F. (2016). Towards a sustainable diet combining economic, environmental and nutritional objectives. *Appetite*, *106*, 48–57. https://doi.org/10.1016/j.appet.2016.02.151

Drewnowski, A. (2020). Analysing the affordability of the EAT–Lancet diet. *The Lancet Global Health*, *8*(1), e6–e7. https://doi.org/10.1016/s2214-109x(19)30502-9

Drewnowski, A., Amanquah, D., & Gavin-Smith, B. (2021). Perspective: How to develop nutrient profiling Models intended for global use: a manual. Advances in Nutrition, 12(3), 609–620. https://doi.org/10.1093/advances/nmab018

ECCC. (2019, June 28). *Taking stock: Reducing food loss and waste in Canada*. Government of Canada. https://www.canada.ca/en/environment-climate-change/services/managing-reducing-waste/food-loss-waste/taking-stock.html#:~:text=An%20estimated%2012%25%20of%20Canada's,facilities%2C%20or%20disposed%20in%20landfills.

Elinder, L. S., Colombo, P. E., Patterson, E., Parlesak, A., & Lindroos, A. K. (2020). Successful implementation of Climate-Friendly, Nutritious, and acceptable school meals in practice: the OPTIMATTM Intervention study. *Sustainability*, *12*(20), 8475. https://doi.org/10.3390/su12208475

Environment and Climate Change Canada. (2022). *Canadian Environmental Sustainability Indicators: Greenhouse Gas Emissions*. www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gasemissions.html.

Espinosa-Marrón, A., Adams, K., Sinno, L., Cantu-Aldana, A., Tamez, M., Marrero, A., Bhupathiraju, S. N., & Champagne, C. M. (2022). Environmental Impact of Animal-Based Food Production and the Feasibility of a Shift Toward Sustainable Plant-Based Diets in the United States. *Frontiers in Sustainability*, *3*. https://doi.org/10.3389/frsus.2022.841106

Esteve-Llorens, X., Martín-Gamboa, M., Iribarren, D., Moreira, M. T., Feijoo, G., & González-García, S. (2020). Efficiency assessment of diets in the Spanish regions: A multi-criteria cross-cutting approach. *Journal of Cleaner Production*, *242*, 118491. https://doi.org/10.1016/j.jclepro.2019.118491

FAO. (2013). Food Wastage Footprint: Impacts on Natural Resources. Summary Report. https://openknowledge.fao.org/server/api/core/bitstreams/1694038d-98f7-40f6-be4b-98782544b9f9/content

Ferguson, E., Darmon, N., Briend, A., & Premachandra, I. M. (2004). Food-Based dietary guidelines can be developed and tested using linear programming analysis. *The Journal of Nutrition*, *134*(4), 951–957. https://doi.org/10.1093/jn/134.4.951

Fernandez, M. A., Bertolo, R. F., Duncan, A. M., Phillips, S. M., Elango, R., Ma, D. W. L., Desroches, S., Grantham, A., & House, J. D. (2020). Translating "protein foods" from the new Canada's Food Guide to consumers: knowledge gaps and recommendations. *Applied physiology, nutrition, and metabolism = Physiologie appliquee, nutrition et metabolisme*, *45*(12), 1311–1323. https://doi.org/10.1139/apnm-2020-0192

Fernandez, M. A., Bertolo, R. F., Duncan, A., Phillips, S. M., Elango, R., David, W. L., Desroches, S., Grantham, A., & House, J. D. (2020). Translating “protein foods” from the new Canada’s Food Guide to consumers: knowledge gaps and recommendations. *Applied Physiology, Nutrition, and Metabolism*, *45*(12), 1311–1323. https://doi.org/10.1139/apnm-2020-0192

Friel, S., Barosh, L. J., & Lawrence, M. (2014). Towards healthy and sustainable food consumption: an Australian case study. *Public Health Nutrition*, *17*(5), 1156–1166. https://doi.org/10.1017/s1368980013001523

Garnett, T. (2014). *What is a sustainable healthy diet?* 31.

Geibel, I., & Freund, F. (2023). The effects of dietary changes in Europe on greenhouse gas emissions and agricultural incomes in Ireland and Denmark. *Environmental Research Letters*, *18*(12), 124026. https://doi.org/10.1088/1748-9326/ad0681

Geough, E. J. M., Little, S. M., Janzen, H. H., McAllister, T. A., McGinn, S. M., & Beauchemin, K. A. (2012). Life-cycle assessment of greenhouse gas emissions from dairy production in Eastern Canada: A case study. *Journal of Dairy Science*, *95*(9), 5164–5175. https://doi.org/10.3168/jds.2011-5229

Godfray, H. C. J., Aveyard, P., Garnett, T., Hall, J. W., Key, T. J., Lorimer, J., Pierrehumbert, R. T., Scarborough, P., Springmann, M., & Jebb, S. A. (2018). Meat consumption, health, and the environment. *Science*, *361*(6399). https://doi.org/10.1126/science.aam5324

González, N., Marquès, M., Nadal, M., & Domingo, J. L. (2020). Meat consumption: Which are the current global risks? A review of recent (2010–2020) evidences. *Food Research International*, *137*, 109341. https://doi.org/10.1016/j.foodres.2020.109341

Green, A., Blatmann, C., Chen, C., & Mathys, A. (2022). The role of alternative proteins and future foods in sustainable and contextually-adapted flexitarian diets. *Trends in Food Science and Technology*, *124*, 250–258. https://doi.org/10.1016/j.tifs.2022.03.026

Green, A., Nemecek, T., Chaudhary, A., & Mathys, A. (2020). Assessing nutritional, health, and environmental sustainability dimensions of agri-food production. Global Food Security, 26, 100406. https://doi.org/10.1016/j.gfs.2020.100406

Grosso, G., Fresán, U., Bes-Rastrollo, M., Marventano, S., & Galvano, F. (2020). Environmental Impact of Dietary Choices: Role of the Mediterranean and Other Dietary Patterns in an Italian Cohort. *International Journal of Environmental Research and Public Health*, *17*(5), 1468. https://doi.org/10.3390/ijerph17051468

Guo, Y., He, P., Searchinger, T., Chen, Y., Springmann, M., Zhou, M., Zhang, X., Zhang, L., & Mauzerall, D. L. (2022). Environmental and human health trade-offs in potential Chinese dietary shifts. *One Earth*, *5*(3), 268–282. https://doi.org/10.1016/j.oneear.2022.02.002

Hadjikakou, M. (2017). Trimming the excess: Environmental impacts of discretionary food consumption in Australia. *Ecological Economics*, *131*, 119–128. https://doi.org/10.1016/j.ecolecon.2016.08.006

Hamamji, S., Ng, A., Ahmed, M., & L'Abbe, M. (2022). Healthfulness of Food Choices As Recommended in Canada's Food Guide 2019 and Cardiometabolic Health in Canadians: Evidence From the National Canadian Health Measures Survey. *Current Developments in Nutrition*, *6*(Supplement_1), 114. https://doi.org/10.1093/cdn/nzac051.030

Hank, I., Rossiter, M. D., & Finch, S. L. (2023). Influence of the 2019 Canada's food Guide on the food environment in childcare and early learning centres. *Canadian Journal of Dietetic Practice and Research*, *84*(2), 93–97. https://doi.org/10.3148/cjdpr-2022-035

Harrison, S., Brassard, D., Lemieux, S., & Lamarche, B. (2019). Consumption and Sources of Saturated Fatty Acids According to the 2019 Canada Food Guide: Data from the 2015 Canadian Community Health Survey. *Nutrients*, *11*(9), 1964. https://doi.org/10.3390/nu11091964

Harrison, S., Lemieux, S., & Lamarche, B. (2022). Assessing the impact of replacing foods high in saturated fats with foods high in unsaturated fats on dietary fat intake among Canadians. *The American Journal of Clinical Nutrition*, *115*(3), 877–885. https://doi.org/10.1093/ajcn/nqab420

Harvard Health. (2014, November 13). Plant-based diet: Nuts, seeds, and legumes can help get you there. https://www.health.harvard.edu/staying-healthy/plant-based-diet-nuts-seeds-and-legumes-can-help-get-you-there

Harvard Health. (2023, May 22). How much water should you drink? https://www.health.harvard.edu/staying-healthy/how-much-water-should-you-drink

Hashemi, F., Mogensen, L., Van Der Werf, H., Cederberg, C., & Knudsen, M. T. (2024). Organic food has lower environmental impacts per area unit and similar climate impacts per mass unit compared to conventional. Communications Earth & Environment, 5(1). https://doi.org/10.1038/s43247-024-01415-6

He, J., Evans, N. M., Liu, H., & Shao, S. (2020). A review of research on plant-based meat alternatives: Driving forces, history, manufacturing, and consumer attitudes. *Comprehensive Reviews in Food Science and Food Safety*, *19*(5), 2639–2656. https://doi.org/10.1111/1541-4337.12610

He, J., Ogden, L. G., Vupputuri, S., Bazzano, L. A., Loria, C. M., & Whelton, P. K. (1999). Dietary Sodium Intake and Subsequent Risk of Cardiovascular Disease in Overweight Adults. *JAMA*, *282*(21), 2027. https://doi.org/10.1001/jama.282.21.2027

Health Canada. (2007, February 5). *History of Canada's Food Guides from 1942 to 2007 - Canada.ca*. Government of Canada. https://www.canada.ca/en/health-canada/services/canada-food-guide/about/history-food-guide.html

Health Canada. (2015, June 12). Health Canada's proposed changes to the daily values (DVS) for use in nutrition labelling. Canada.ca. https://www.canada.ca/en/health-canada/services/food-nutrition/public-involvement-partnerships/technical-consultation-proposed-changes-daily-values-use-nutrition-labelling/consultation.html

Health Canada. (2019, January 22). *Food guide snapshot - Canada's Food Guide*. Government of Canada. https://food-guide.canada.ca/en/food-guide-snapshot/

Health Canada. (2020, February 24). National nutritious food basket. Canada.ca. https://www.canada.ca/en/health-canada/services/food-nutrition/food-nutrition-surveillance/national-nutritious-food-basket.html

Health Canada. (2022, July 13). *Canadian Community Health Survey*. Government of Canada. https://www.canada.ca/en/health-canada/services/food-nutrition/food-nutrition-surveillance/health-nutrition-surveys/canadian-community-health-survey-cchs.html

Health Canada. (2023, January 3). *Canadian Community Health Survey - Annual Component*. Government of Canada. https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=3226

Heller, M. C., Keoleian, G. A., & Willett, W. C. (2013). Toward a life cycle-based, diet-level framework for food environmental impact and nutritional quality assessment: a critical review. *Environmental science & technology*, *47*(22), 12632–12647. https://doi.org/10.1021/es4025113

Heller, M., & Keoleian, G. A. (2003). Assessing the sustainability of the US food system: a life cycle perspective. *Agricultural Systems*, *76*(3), 1007–1041. https://doi.org/10.1016/s0308-521x(02)00027-6

Heller, M., Narayanan, T., Meyer, R., & Keoleian, G. (2016). *Category-Level Product Environmental Footprints of Foods: Food Life Cycle Assessment Literature Review*. University of Michigan Center for Sustainable Systems.

Hicks, T., Knowles, S. O., & Farouk, M. M. (2018). Global Provisioning of Red Meat for Flexitarian Diets. *Frontiers in Nutrition*, *5*. https://doi.org/10.3389/fnut.2018.00050

Hirvonen, K., Bai, Y., Headey, D., & Masters, W. A. (2020). Affordability of the EAT–Lancet reference diet: a global analysis. *The Lancet Global Health*, *8*(1), e59–e66. https://doi.org/10.1016/s2214-109x(19)30447-4

Huangfu, Q., & Hall, J. a. J. (2018). Parallelizing the dual revised simplex method. Mathematical Programming Computation, 10(1), 119–142. https://doi.org/10.1007/s12532-017-0130-5

Hutchinson, J. M., Williams, T. E., Westaway, A. M., Bédard, A., Pitre, C., Lemieux, S., Dodd, K. W., Lamarche, B., Guenther, P. M., Haines, J., Wallace, A., Martín, A., Louzada, M., Jessri, M., Olstad, D. L., Prowse, R., Simpson, J. R., Vena, J. E., & Kirkpatrick, S. I. (2023). Development of the Canadian Food Intake Screener to assess alignment of adults' dietary intake with the 2019 Canada's Food Guide healthy food choices recommendations. *Applied Physiology, Nutrition, and Metabolism*, *48*(8), 603–619. https://doi.org/10.1139/apnm-2023-0019

Janssen, M., Chang, B. L., Hristov, H., Pravst, I., Profeta, A., & Millard, J. (2021). Changes in Food Consumption During the COVID-19 Pandemic: Analysis of Consumer Survey Data From the First Lockdown Period in Denmark, Germany, and Slovenia. *Frontiers in Nutrition*, *8*. https://doi.org/10.3389/fnut.2021.635859

Jansson, T., Giannakis, E., Kushta, J., Hristov, J., Sahoo, A., & Domínguez, I. P. (2022). Co-benefits of a flexitarian diet for air quality and human health in Europe. *Ecological Economics*, *191*, 107232. https://doi.org/10.1016/j.ecolecon.2021.107232

Jensen, J., Saxe, H., & Denver, S. (2015). Cost-Effectiveness of a New Nordic Diet as a Strategy for Health Promotion. *International Journal of Environmental Research and Public Health*, *12*(7), 7370–7391. https://doi.org/10.3390/ijerph120707370

Jessri, M., Nishi, S., & L'Abbé, M. (2015). Assessing the Nutritional Quality of Diets of Canadian Adults Using the 2014 Health Canada Surveillance Tool Tier System. *Nutrients*, *7*(12), 10447–10468. https://doi.org/10.3390/nu7125543

Johnston, J., Fanzo, J., & Cogill, B. (2014). Understanding Sustainable Diets: A Descriptive Analysis of the Determinants and Processes That Influence Diets and Their Impact on Health, Food Security, and Environmental Sustainability. *Advances in Nutrition*, *5*(4), 418–429. https://doi.org/10.3945/an.113.005553

Jolliet, O. (2022). Integrating Dietary Impacts in Food Life Cycle Assessment. *Frontiers in Nutrition*, *9*. https://doi.org/10.3389/fnut.2022.898180

Jones, A. D., Hoey, L., Blesh, J., Miller, L., Green, A., & Shapiro, L. F. (2016). A Systematic Review of the Measurement of Sustainable Diets. *Advances in nutrition (Bethesda, Md.)*, *7*(4), 641–664. https://doi.org/10.3945/an.115.011015

Jones, R., Wham, C., & Burlingame, B. (2019). New Zealand's Food System Is Unsustainable: A Survey of the Divergent Attitudes of Agriculture, Environment, and Health Sector Professionals Towards Eating Guidelines. *Frontiers in Nutrition*, *6*. https://doi.org/10.3389/fnut.2019.00099

Kaplan, J. (2010, February 19). *Eat Green: Our Everyday Food Choices Affect Global Warming and the Environment*. NRDC. https://www.nrdc.org/resources/eat-green-our-everyday-food-choices-affect-global-warming-and-environment

Kesse-Guyot, E., Chaltiel, D., Wang, J., Pointereau, P., Langevin, B., Allès, B., Rebouillat, P., Lairon, D., Vidal, R., Mariotti, F., Egnell, M., Touvier, M., Julia, C., Baudry, J., & Hercberg, S. (2020). Sustainability analysis of French dietary guidelines using multiple criteria. *Nature Sustainability*, *3*(5), 377–385. https://doi.org/10.1038/s41893-020-0495-8

Kesse-Guyot, E., Rebouillat, P., Brunin, J., Langevin, B., Allès, B., Touvier, M., Herçberg, S., Fouillet, H., Huneau, J., Mariotti, F., Lairon, D., Pelletier, P., & Baudry, J. (2021). Environmental and nutritional analysis of the EAT-Lancet diet at the individual level: insights from the NutriNet-Santé study. *Journal of Cleaner Production*, *296*, 126555. https://doi.org/10.1016/j.jclepro.2021.126555

Kpogo, A. L., Jose, J., Panisson, J., Predicala, B., Alvarado, A., Agnew, J., Sprenger, C., & Beaulieu, D. A. (2021). 27 Greenhouse Gas Emissions and a Partial Life Cycle Assessment When Growing Pigs Are Fed High Wheat Millrun Diets. *Journal of Animal Science*, *99*(Supplement_1), 24–25. https://doi.org/10.1093/jas/skab054.043

Kraak, V. I., & Aschemann-Witzel, J. (2024). The Future of Plant-Based Diets: Aligning Healthy Marketplace Choices with Equitable, Resilient, and Sustainable Food Systems. Annual Review of Public Health, 45(1), 253–275. https://doi.org/10.1146/annurev-publhealth-060722-032021

Laila, A., Leme, A. C. B., Hou, S., WL, D., & Haines, J. (2023). Perceived challenges and strategies to achieve Canada's Food Guide recommendation to "Cook more often": Findings from parents of young children. *Appetite*, *182*, 106413. https://doi.org/10.1016/j.appet.2022.106413

Lee, A., McLeod-Kilmurray, H., & Chalifour, N. (2017, January 30). *Canada's Food Guide update needs to address sustainability*. Policy Options. https://policyoptions.irpp.org/fr/magazines/janvier-2017/canadas-food-guide-update-needs-to-address-sustainability/

Leme, A. C. B., Laila, A., Hou, S., Fisberg, R. M., WL, D., Fisberg, M., & Haines, J. (2022). Perceptions of the 2019 Canada's Food Guide: a qualitative study with parents from Southwestern Ontario. *Applied Physiology, Nutrition, and Metabolism*, *47*(1), 34–40. https://doi.org/10.1139/apnm-2021-0414

Li, M., Jia, N., Lenzen, M., Malik, A., Wei, L., Jin, Y., & Raubenheimer, D. (2022). Global food-miles account for nearly 20% of total food-systems emissions. *Nature Food*, *3*(6), 445–453. https://doi.org/10.1038/s43016-022-00531-w

Liu, A. G., Ford, N. A., Hu, F. B., Zelman, K. M., Mozaffarian, D., & Kris-Etherton, P. M. (2017). A healthy approach to dietary fats: understanding the science and taking action to reduce consumer confusion. Nutrition Journal, 16(1). https://doi.org/10.1186/s12937-017-0271-4

Macdiarmid, J. I. (2013). Is a healthy diet an environmentally sustainable diet? *Proceedings of the Nutrition Society*, *72*(1), 13–20. https://doi.org/10.1017/s0029665112002893

Macdiarmid, J. I., Kyle, J., Horgan, G. W., Loe, J., Fyfe, C., Johnstone, A., & McNeill, G. (2012). Sustainable diets for the future: can we contribute to reducing greenhouse gas emissions by eating a healthy diet? American Journal of Clinical Nutrition, 96(3), 632–639. https://doi.org/10.3945/ajcn.112.038729

Macdiarmid, J. I., Kyle, J., Horgan, G., Loe, J., Fyfe, C., Johnstone, A. M., & McNeill, G. (2012). Sustainable diets for the future: can we contribute to reducing greenhouse gas emissions by eating a healthy diet? *The American Journal of Clinical Nutrition*, *96*(3), 632–639. https://doi.org/10.3945/ajcn.112.038729

Maillot, M., Darmon, N., & Drewnowski, A. (2010). Are the lowest-cost healthful food plans culturally and socially acceptable? *Public Health Nutrition*, *13*(8), 1178–1185. https://doi.org/10.1017/s1368980009993028

Maillot, M., Ferguson, E., Drewnowski, A., & Darmon, N. (2008). Nutrient Profiling Can Help Identify Foods of Good Nutritional Quality for Their Price: a Validation Study with Linear Programming. *The Journal of Nutrition*, *138*(6), 1107–1113. https://doi.org/10.1093/jn/138.6.1107

Mangone, L., Sacerdote, C., Laine, J. E., Masala, G., Bendinelli, B., Panico, S., Chiodini, P., Grioni, S., Tumino, R., Petiti, L., & Víneis, P. (2023). Food, Health, and Mitigation of Climate change in Italy. *PubMed*, *47*(3), 32–38. https://doi.org/10.19191/ep23.3.s1.a560.038

Marlow, H. J., Harwatt, H., Soret, S., & Sabaté, J. (2015). Comparing the water, energy, pesticide and fertilizer usage for the production of foods consumed by different dietary types in California. *Public Health Nutrition*, *18*(13), 2425–2432. https://doi.org/10.1017/S1368980014002833

Masino, T., Colombo, P. E., Reis, K., Tetens, I., & Parlesak, A. (2023). Climate-friendly, health-promoting, and culturally acceptable diets for German adult omnivores, pescatarians, vegetarians, and vegans – a linear programming approach. *Nutrition*, *109*, 111977. https://doi.org/10.1016/j.nut.2023.111977

Medlin, C., & Skinner, J. D. (1988). Individual dietary intake methodology: A 50-year review of progress. *Journal of the American Dietetic Association*, *88*(10), 1250–1257. https://doi.org/10.1016/s0002-8223(21)07993-1

Mertens, E., Kuijsten, A., van Zanten, H. HE., Kaptijn, G., Dofková, M., Mistura, L., D'Addezio, L., Turrini, A., Dubuisson, C., Havard, S., Trolle, E., Geleijnse, J. M., & Veer, P. van 't. (2019). Dietary choices and environmental impact in four European countries. *Journal of Cleaner Production*, *237*, 117827. https://doi.org/10.1016/j.jclepro.2019.117827

Moberg, E., Potter, H. K., Wood, A., Hansson, P., & Röös, E. (2020). Benchmarking the Swedish diet relative to Global and National Environmental Targets—Identification of indicator limitations and data gaps. Sustainability, 12(4), 1407. https://doi.org/10.3390/su12041407

Monsivais, P., Scarborough, P., Lloyd, T., Mizdrak, A., Luben, R., Mulligan, A. A., Wareham, N. J., & Woodcock, J. (2015). Greater accordance with the Dietary Approaches to Stop Hypertension dietary pattern is associated with lower diet-related greenhouse gas production but higher dietary costs in the United Kingdom. *The American Journal of Clinical Nutrition*, *102*(1), 138–145. https://doi.org/10.3945/ajcn.114.090639

Monteiro, C. A., Cannon, G., Moubarac, J., Martins, A. M., Martins, C., Garzillo, J. M. F., Canella, D. S., Baraldi, L. G., Barciotte, M. L., Da Costa Louzada, M. L., Levy, R. B., Claro, R. M., & Jaime, P. C. (2015). Dietary guidelines to nourish humanity and the planet in the twenty-first century. A blueprint from Brazil. *Public Health Nutrition*, *18*(13), 2311–2322. https://doi.org/10.1017/s1368980015002165

Muñoz, I., Canals, L. M. I., & Fernández-Alba, A. R. (2010). Life cycle assessment of the average Spanish diet including human excretion. *International Journal of Life Cycle Assessment*, *15*(8), 794–805. https://doi.org/10.1007/s11367-010-0188-z

Muñoz-Martínez, J., Elías, R. A., Batlle-Bayer, L., Cussó-Parcerisas, I., & Álvarez, E. C. (2023). Optimizing sustainable, affordable and healthy diets and estimating the impact of plant-based substitutes to milk and meat: A case study in Spain. *Journal of Cleaner Production*, *424*, 138775. https://doi.org/10.1016/j.jclepro.2023.138775

Nelson, M. E., Hamm, M. W., Hu, F. B., Abrams, S. A., & Griffin, T. S. (2016, November). Alignment of Healthy Dietary Patterns and Environmental Sustainability: A Systematic Review. *Advances in Nutrition: An International Review Journal*, *7*(6), 1005–1025. https://doi.org/10.3945/an.116.012567

Nemecek, T., Jungbluth, N., Canals, L. M. I., & Schenck, R. (2016). Environmental impacts of food consumption and nutrition: where are we and what is next? *International Journal of Life Cycle Assessment*, *21*(5), 607–620. https://doi.org/10.1007/s11367-016-1071-3

O'Donnell, M., Mente, A., & Yusuf, S. (2015). Sodium Intake and Cardiovascular Health. *Circulation Research*, *116*(6), 1046–1057. https://doi.org/10.1161/circresaha.116.303771

Ocké, M. C. (2013). Evaluation of methodologies for assessing the overall diet: dietary quality scores and dietary pattern analysis. Proceedings of the Nutrition Society, 72(2), 191–199. https://doi.org/10.1017/s0029665113000013

Ontario Ministry of Health. (2021, October 21). *Calories on menus*. ontario.ca. https://www.ontario.ca/page/calories-menus#:~:text=However%2C%20individual%20needs%20vary.,individual%20calorie%20needs%20may%20vary

Patel, P., & MannionRN, C. (2021). Maternal impressions of the new 2019 Canadian food Guide snapshot. *Canadian Journal of Dietetic Practice and Research*, *82*(4), 192–195. https://doi.org/10.3148/cjdpr-2021-014

Pelletier, N. (2017). Life cycle assessment of Canadian egg products, with differentiation by hen housing system type. *Journal of Cleaner Production*, *152*, 167–180. https://doi.org/10.1016/j.jclepro.2017.03.050

Pelletier, N. (2017). Life cycle assessment of Canadian egg products, with differentiation by hen housing system type. Journal of Cleaner Production, 152, 167–180. https://doi.org/10.1016/j.jclepro.2017.03.050

Pelletier, N., Tyedmers, P., Sonesson, U., Scholz, A., Ziegler, F., Flysjo, A., Kruse, S., Cancino, B., & Silverman, H. (2009). Not All Salmon Are Created Equal: Life Cycle Assessment (LCA) of Global Salmon Farming Systems. *Environmental Science & Technology*, *43*(23), 8730–8736. https://doi.org/10.1021/es9010114

Perignon, M., & Darmon, N. (2021). Advantages and limitations of the methodological approaches used to study dietary shifts towards improved nutrition and sustainability. *Nutrition Reviews*, *80*(3), 579–597. https://doi.org/10.1093/nutrit/nuab091P

Perignon, M., Vieux, F., Soler, L., Masset, G., & Darmon, N. (2017). Improving diet sustainability through evolution of food choices: review of epidemiological studies on the environmental impact of diets. *Nutrition Reviews*, *75*(1), 2–17. https://doi.org/10.1093/nutrit/nuw043

Perreault, M., Wallace, A., Martin, A. R., Sadowski, A., Laila, A., Lemieux, S., Hutchinson, J. M., Kirkpatrick, S. I., Simpson, J. R., Guenther, P. M., Lamarche, B., Jessri, M., Louzada, M., Olstad, D. L., Prowse, R., Vatanparast, H., & Haines, J. (2023). Construct

validity and reliability of the Canadian Eating Practices Screener to assess eating practices based on 2019 Canada's Food Guide recommendations. *Applied Physiology, Nutrition, and Metabolism*, *48*(12), 919–931. https://doi.org/10.1139/apnm-2023-0080

Pesonen, H., Ekvall, T., Fleischer, G., Huppes, G., Jahn, C., Kłos, Z., Rebitzer, G., Sonnemann, G., Tintinelli, A., Weidema, B. P., & Wenzel, H. (2000). Framework for scenario development in LCA. *International Journal of Life Cycle Assessment*, *5*(1). https://doi.org/10.1007/bf02978555

Pfisterer, K. J., Amelard, R., Keller, H., & Wong, A. (2023). Characterizing Canadian long-term care home consumed foods and their inflammatory potential: a secondary analysis. *BMC Public Health*, *23*(1). https://doi.org/10.1186/s12889-022-14934-8

Pimentel, D., & Pimentel, M. (2003). Sustainability of meat-based and plant-based diets and the environment. *The American Journal of Clinical Nutrition*, *78*(3), 660S-663S. https://doi.org/10.1093/ajcn/78.3.660s

Point, E., Tyedmers, P., & Naugler, C. (2012). Life cycle environmental impacts of wine production and consumption in Nova Scotia, Canada. *Journal of Cleaner Production*, *27*, 11–20. https://doi.org/10.1016/j.jclepro.2011.12.035

Poti, J. M., Braga, B., & Qin, B. (2017). Ultra-processed Food Intake and Obesity: What Really Matters for Health—Processing or Nutrient Content? *Current Obesity Reports*, *6*(4), 420–431. https://doi.org/10.1007/s13679-017-0285-4

Prag, A. A., & Henriksen, C. B. (2020). Transition from Animal-Based to Plant-Based Food Production to Reduce Greenhouse Gas Emissions from Agriculture—The Case of Denmark. *Sustainability*, *12*(19), 8228. https://doi.org/10.3390/su12198228

Prowse, R., Doan, N., Philipneri, A., Thielman, J., Hack, S., Harrington, D., & Jessri, M. (2022). Creating "Plates" to evaluate Canadians' dietary intake in relation to the 2019 Canada's Food Guide. *Canadian Journal of Dietetic Practice and Research*, *83*(4), 152–159. https://doi.org/10.3148/cjdpr-2022-010

Prowse, R., Doan, N., Philipneri, A., Thielman, J., Hack, S., Harrington, D. W., & Jessri, M. (2022). Creating "Plates" to evaluate Canadians' dietary intake in relation to the 2019 Canada's Food Guide. Canadian Journal of Dietetic Practice and Research, 83(4), 152–159. https://doi.org/10.3148/cjdpr-2022-010

Ramuscak, A. V., Duncan, A., WL, D., & Haines, J. (2023). Parents' knowledge of the 2019 Canada's Food Guide recommendations. *Applied Physiology, Nutrition, and Metabolism*, *48*(12), 1015–1018. https://doi.org/10.1139/apnm-2023-0159

Ramuscak, A. V., Ma, D. W. L., Forbes, L. E., Duncan, A. M., Sadowski, A., & Haines, J. (2022). Comparing the perceptions and opinions of the 2007 and 2019 Canada's food guides among parents of young children. *Frontiers in public health*, *10*, 944648. https://doi.org/10.3389/fpubh.2022.944648

Rana, H., Mallet, M., Gonzalez, A., Verreault, M., & St-Pierre, S. (2021). Free sugars consumption in Canada. *Nutrients*, *13*(5), 1471. https://doi.org/10.3390/nu13051471

Ravelli, M. N., & Schoeller, D. A. (2020). Traditional Self-Reported Dietary Instruments Are Prone to Inaccuracies and New Approaches Are Needed. *Frontiers in Nutrition*, *7*. https://doi.org/10.3389/fnut.2020.00090

Reijnders, L., & Soret, S. (2003). Quantification of the environmental impact of different dietary protein choices. *The American journal of clinical nutrition*, *78*(3 Suppl), 664S–668S. https://doi.org/10.1093/ajcn/78.3.664S

Reynolds, A., Mhurchú, C. N., Kok, Z., & Cleghorn, C. (2023). The neglected potential of red and processed meat replacement with alternative protein sources: simulation modelling and systematic review. *EClinicalMedicine*, *56*, 101774. https://doi.org/10.1016/j.eclinm.2022.101774

Rochefort, G., Brassard, D., Paquette, M., Robitaille, J., Lemieux, S., Provencher, V., & Lamarche, B. (2022). Adhering to Canada's Food Guide Recommendations on Healthy Food Choices Increases the Daily Diet Cost: Insights from the PREDISE Study. *Nutrients*, *14*(18), 3818. https://doi.org/10.3390/nu14183818

Röös, E., Karlsson, H., Witthöft, C., & Sundberg, C. (2015). Evaluating the sustainability of diets–combining environmental and nutritional aspects. *Environmental Science & Policy*, *47*, 157–166. https://doi.org/10.1016/j.envsci.2014.12.001

Rose, D., Heller, M. C., Willits-Smith, A. M., & Meyer, R. J. (2019). Carbon footprint of self-selected US diets: Nutritional, demographic, and behavioral correlates. *The American Journal of Clinical Nutrition*, *109*(3), 526–534. https://doi.org/10.1093/ajcn/nqy327

Rosi, A., Mena, P., Pellegrini, N., Turroni, S., Neviani, E., Haroutounian, S. A., Di Cagno, R., Ruini, L., Ciati, R., Angelino, D., Maddock, J., Gobbetti, M., Brighenti, F., Del Rio, D., & Scazzina, F. (2017). Environmental impact of omnivorous, ovo-lacto-vegetarian, and vegan diet. *Scientific Reports*, *7*(1). https://doi.org/10.1038/s41598-017-06466-8

Saarinen, M., Fogelholm, M., Tahvonen, R., & Kurppa, S. (2017). Taking nutrition into account within the life cycle assessment of food products. *Journal of Cleaner Production*, *149*, 828–844. https://doi.org/10.1016/j.jclepro.2017.02.062

Sakkas, H., Bozidis, P., Touzios, C., Kolios, D., Athanasiou, G. N., Athanasopoulou, E., Gerou, I., & Gartzonika, C. (2020). Nutritional Status and the Influence of the Vegan Diet on the Gut Microbiota and Human Health. *Medicina-Lithuania*, *56*(2), 88. https://doi.org/10.3390/medicina56020088

Sanderson, V., Bamber, N., & Pelletier, D. N. (2019). Cradle-to-market life cycle assessment of Okanagan (Canada) cherries: Helicopters, seasonal migrant labour and flying fruit. *Journal of Cleaner Production*, *229*, 1283–1293. https://doi.org/10.1016/j.jclepro.2019.04.398

Santo, R., Kim, B. F., Goldman, S. E., Dutkiewicz, J., Biehl, E., Bloem, M. W., Neff, R. A., & Nachman, K. E. (2020). Considering Plant-Based Meat Substitutes and Cell-Based Meats: A Public Health and Food Systems Perspective. *Frontiers in Sustainable Food Systems*, *4*. https://doi.org/10.3389/fsufs.2020.00134

Seed, B. (2015). Sustainability in the Qatar national dietary guidelines, among the first to incorporate sustainability principles. *Public Health Nutrition*, *18*(13), 2303–2310. https://doi.org/10.1017/s1368980014002110

Selvey, L. A., & Carey, M. G. (2013). Australia's dietary guidelines and the environmental impact of food "from paddock to plate." *The Medical Journal of Australia*, *198*(1), 18–19. https://doi.org/10.5694/mja12.10528

Semba, R. D., De Pee, S., Kim, B. F., McKenzie, S., Nachman, K. E., & Bloem, M. W. (2020). Adoption of the 'planetary health diet' has different impacts on countries' greenhouse gas emissions. *Nature Food*, *1*(8), 481–484. https://doi.org/10.1038/s43016-020-0128-4

Serra-Majem, L., Tomaino, L., Dernini, S., Berry, E. M., Lairon, D., De La Cruz, J. N., Bach-Faig, A., Donini, L. M., Medina, F. X., Belahsen, R., Piscopo, S., Capone, R., Aranceta-Bartrina,

J., La Vecchia, C., & Trichopoulou, A. (2020). Updating the Mediterranean Diet Pyramid towards Sustainability: Focus on Environmental Concerns. *International Journal of Environmental Research and Public Health*, *17*(23), 8758. https://doi.org/10.3390/ijerph17238758

Shahbandeh, M. (2022, June 28). *How often Canadians consume organic products 2020*. Statista. https://www.statista.com/statistics/1143248/organic-food-consumption-canada/

Shahbandeh, M. (2024, January 10). Organic food market in Canada- statistics & facts. Statista. https://www.statista.com/topics/4235/organic-food-market-in-canada/#topicOverview

Sherwood, J. N., Clabeaux, R., & Carbajales-Dale, M. (2017). An extended environmental input–output lifecycle assessment model to study the urban food–energy–water nexus. *Environmental Research Letters*, *12*(10), 105003. https://doi.org/10.1088/1748-9326/aa83f0

Smith, V., 1959. Linear programming models for the determination of palatable human diets. J. Farm Econ. 41, 272–283.

Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., De Vries, W., Vermeulen, S. J., Herrero, M., Carlson, K. M., Jonell, M., Troell, M., DeClerck, F., Gordon, L. J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., . . . Willett, W. (2018). Options for keeping the food system within environmental limits. Nature, 562(7728), 519–525. https://doi.org/10.1038/s41586-018-0594-0

Springmann, M., Wiebe, K., Mason-D'Croz, D., Sulser, T. B., Rayner, M., & Scarborough, P. (2018). Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. *The Lancet Planetary Health*, *2*(10), e451–e461. https://doi.org/10.1016/s2542-5196(18)30206-7

Stanton, A. (2024). Unacceptable use of substandard metrics in policy decisions which mandate large reductions in animal-source foods. *Npj Science of Food*, *8*(1). https://doi.org/10.1038/s41538-024-00249-y

Statistics Canada. (2022, July 4). *Recent facts about certified organic fruits and vegetables in Canada, 2021*. https://www150.statcan.gc.ca/n1/daily-quotidien/220714/dq220714d-eng.htm

Statistics Canada. (2024, June 19). Population estimates, quarterly. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710000901

Stewart, K., Balmford, A., Scheelbeek, P., Doherty, A., & Garnett, E. (2023). Changes in greenhouse gas emissions from food supply in the United Kingdom. *Journal of Cleaner Production*, *410*, 137273. https://doi.org/10.1016/j.jclepro.2023.137273

Stone, T. F., Thompson, J. R., Rosentrater, K. A., & Liebman, M. (2023). Modeling a localized metropolitan food system in the Midwest USA: Life cycle impacts of scenarios for Des Moines, Iowa. *Science of the Total Environment*, *865*, 161095. https://doi.org/10.1016/j.scitotenv.2022.161095

Subar, A. F., Freedman, L. S., Tooze, J. A., Kirkpatrick, S. I., Boushey, C., Neuhouser, M. L., Thompson, F. E., Potischman, N., Guenther, P. M., Tarasuk, V., Reedy, J., & Krebs-Smith, S. M. (2015). Addressing Current Criticism Regarding the Value of Self-Report Dietary Data ,. *The Journal of Nutrition*, *145*(12), 2639–2645. https://doi.org/10.3945/jn.115.219634

Sun, Z., Scherer, L., Tukker, A., Spawn-Lee, S. A., Brückner, M., Gibbs, H. K., & Behrens, P. (2022). Dietary change in high-income nations alone can lead to substantial double climate dividend. *Nature Food*, *3*(1), 29–37. https://doi.org/10.1038/s43016-021-00431-5

Sun, Z., Scherer, L., Zhang, Q., & Behrens, P. (2022). Adoption of plant-based diets across Europe can improve food resilience against the Russia–Ukraine conflict. *Nature Food*, *3*(11), 905–910. https://doi.org/10.1038/s43016-022-00634-4

Temme, E. H., Toxopeus, I. B., Kramer, G. F., Brosens, M. C., Drijvers, J. M., Tyszler, M., & Ocké, M. C. (2015). Greenhouse gas emission of diets in the Netherlands and associations with food, energy and macronutrient intakes. *Public Health Nutrition*, *18*(13), 2433–2445. https://doi.org/10.1017/S1368980014002821

Temme, E. H., van der Voet, H., Thissen, J. T., Verkaik-Kloosterman, J., van Donkersgoed, G., & Nonhebel, S. (2013). Replacement of meat and dairy by plant-derived foods: Estimated

effects on land use, iron and SFA intakes in young Dutch adult females. *Public Health Nutrition*, *16*(10), 1900–1907. https://doi.org/10.1017/S1368980013000232

Topcu, B., Dias, G. M., & Mollaei, S. (2022). Ten-Year Changes in Global Warming Potential of Dietary Patterns Based on Food Consumption in Ontario, Canada. *Sustainability*, *14*(10), Article 10. https://doi.org/10.3390/su14106290

Toronto Board of Health. (2019, September 9). *Canada's New Food Guide - Implications and Opportunities for Action*. City of Toronto. https://www.toronto.ca/legdocs/mmis/2019/hl/bgrd/backgroundfile-137354.pdf

Tsiampalis, T., Faka, A., Panagiotakos, D. B., Psaltopoulou, T., Pitsavos, C., Chalkias, C., & Panagiotakos, D. B. (2021). The impact of socioeconomic and environmental determinants on Mediterranean diet adherence: a municipal-level spatial analysis in Athens metropolitan area, Greece. *International Journal of Food Sciences and Nutrition*, *72*(2), 259–270. https://doi.org/10.1080/09637486.2020.1791057

Tukker, A., Goldbohm, R. A., de Koning, A., Verheijden, M., Kleijn, R., Wolf, O., Pérez-Domínguez, I., & Rueda-Cantuche, J. M. (2011). Environmental impacts of changes to healthier diets in Europe. *Ecological Economics*, *70*(10), 1776–1788. https://doi.org/10.1016/j.ecolecon.2011.05.001

Tuso, P., Ismail, M. A., Ha, B., & Bartolotto, C. (2013). Nutritional Update for Physicians: Plant-Based Diets. *The Permanente Journal*, *17*(2), 61–66. https://doi.org/10.7812/tpp/12-085

Tyszler, M., Kramer, G. F. H., & Blonk, H. (n.d.). *Just eating healthier is not enough: Studying the environmental impact of different diet scenarios for the Netherlands by Linear Programming*. 12.

USDA. (2014, March). *A Series of Systematic Reviews on the Relationship Between Dietary Patterns and Health Outcomes*. USDA Nutrition Evidence Systematic Review. https://nesr.usda.gov/sites/default/files/2019-06/DietaryPatternsReport-FullFinal2.pdf

USDA. (2023, January 11). *Food Availability (Per Capita) Data System*. USDA ERS. https://www.ers.usda.gov/data-products/food-availability-per-capita-data-system/

Vallejo, R. M., Schulz, C., Van De Locht, K., Oluwagbemigun, K., Alexy, U., & Nöthlings, U. (2022). Associations of Adherence to a Dietary Index Based on the EAT–Lancet Reference Diet with Nutritional, Anthropometric, and Ecological Sustainability Parameters: Results from the German DONALD Cohort Study. *The Journal of Nutrition*, *152*(7), 1763–1772. https://doi.org/10.1093/jn/nxac094

Van Dooren, C. (2018). A review of the use of linear programming to optimize diets, nutritiously, economically and environmentally. *Frontiers in Nutrition*, *5*. https://doi.org/10.3389/fnut.2018.00048

Van Dooren, C., & Aiking, H. (2015). Defining a nutritionally healthy, environmentally friendly, and culturally acceptable Low Lands Diet. *The International Journal of Life Cycle Assessment*, *21*(5), 688–700. https://doi.org/10.1007/s11367-015-1007-3

Van Dooren, C., & Aiking, H. (2015). Defining a nutritionally healthy, environmentally friendly, and culturally acceptable Low Lands Diet. The International Journal of Life Cycle Assessment, 21(5), 688–700. https://doi.org/10.1007/s11367-015-1007-3

Van Dooren, C., Tyszler, M., Kramer, G. F. H., & Aiking, H. (2015). Combining Low Price, Low Climate Impact and High Nutritional Value in One Shopping Basket through Diet Optimization by Linear Programming. Sustainability, 7(9), 12837–12855. https://doi.org/10.3390/su70912837

van Dooren, C., Tyszler, M., Kramer, G., & Aiking, H. (2015). Combining Low Price, Low Climate Impact and High Nutritional Value in One Shopping Basket through Diet Optimization by Linear Programming. *Sustainability*, *7*(9), 12837–12855. https://doi.org/10.3390/su70912837

Van Dooren, C., Tyszler, M., Kramer, G., & Aiking, H. (2015). Combining Low Price, Low Climate Impact and High Nutritional Value in One Shopping Basket through Diet Optimization by Linear Programming. *Sustainability*, *7*(9), 12837–12855. https://doi.org/10.3390/su70912837

Vázquez-Rowe, I., Larrea-Gallegos, G., Villanueva-Rey, P., & Gilardino, A. (2017). Climate change mitigation opportunities based on carbon footprint estimates of dietary patterns in Peru. *PLOS ONE*, *12*(11), e0188182. https://doi.org/10.1371/journal.pone.0188182

Veeramani, A. (2015). *Carbon footprinting dietary choices in Ontario: a life cycle approach towards sustainable, healthy and socially acceptable dietary patterns*. University of Waterloo.

Veeramani, A., Dias, G., & Kirkpatrick, S. (2016). *Life cycle approach to modeling nutritionally-balanced climate-friendly and socially-viable dietary patterns in Ontario Canada.pdf*. http://lcafood2016.org/wp-content/uploads/2016/10/LCA2016_BookOfAbstracts.pdf#964

Veeramani, A., Dias, G., & Kirkpatrick, S. I. (2017). Carbon footprint of dietary patterns in Ontario, Canada: A case study based on actual food consumption. *Journal of Cleaner Production*, *162*, 1398–1406. https://doi.org/10.1016/j.jclepro.2017.06.025

Veeramani, Anastasia, Goretty Dias, and Sharon Kirkpatrick. "A Life Cycle Approach to Modeling Nutritionally Balanced, Climate-Friendly and Socially Viable Dietary Patterns in Ontario, Canada." In Unknown. Dublin, Ireland, 2016.

Verkerk, R. (2019). EAT-Lancet - is there such a thing as "one-size-fits-all" sustainability? In *Journal of Holistic Healthcare* (Vol. 16, Issue 3, pp. 15–16). https://bhma.org/wp-content/uploads/2019/10/EAT-Lancet-response-.pdf

Vieux, F., Perignon, M., Gazan, R., & Darmon, N. (2018). Dietary changes needed to improve diet sustainability: are they similar across Europe? European Journal of Clinical Nutrition, 72(7), 951–960. https://doi.org/10.1038/s41430-017-0080-z

Vieux, F., Soler, L., Touazi, D., & Darmon, N. (2013). High nutritional quality is not associated with low greenhouse gas emissions in self-selected diets of French adults. *The American Journal of Clinical Nutrition*, *97*(3), 569–583. https://doi.org/10.3945/ajcn.112.035105

Vinci, G., Maddaloni, L., Prencipe, S. A., Ruggeri, M., & Di Loreto, M. V. (2022). A Comparison of the Mediterranean Diet and Current Food Patterns in Italy: A Life Cycle Thinking Approach for a Sustainable Consumption. *International Journal of Environmental Research and Public Health*, *19*(19), 12274. https://doi.org/10.3390/ijerph191912274

Virtanen, M., Ferrie, J. E., Singh-Manoux, A., Shipley, M. J., Stansfeld, S., Marmot, M., Ahola, K., Vahtera, J., & Kivimäki, M. (2011). Long working hours and symptoms of anxiety and depression: a 5-year follow-up of the Whitehall II study. *Psychological Medicine*, *41*(12), 2485–2494. https://doi.org/10.1017/s0033291711000171

Virtanen, P., Gommers, R., Oliphant, T., Haberland, M., Reddy, T., Cournapeau, D., Burovski, E., Peterson, P., Weckesser, W., Bright, J., Van Der Walt, S., Brett, M., Wilson, J., Millman, K., Mayorov, N., Nelson, A., Jones, E., Kern, R., Larson, E., . . . Vázquez-Baeza, Y. (2020). SciPy 1.0: fundamental algorithms for scientific computing in Python. Nature Methods, 17(3), 261–272. https://doi.org/10.1038/s41592-019-0686-2

Virtanen, Y., Kurppa, S., Saarinen, M., Katajajuuri, J., Usva, K., Mäenpää, I., Mäkelä, J., Grönroos, J., & Nissinen, A. (2011). Carbon footprint of food – approaches from national input–output statistics and a LCA of a food portion. *Journal of Cleaner Production*, *19*(16), 1849–1856. https://doi.org/10.1016/j.jclepro.2011.07.001

Vitale, M., Giosuè, A., Vaccaro, O., & Riccardi, G. (2021). Recent trends in dietary habits of the Italian population: Potential impact on health and the environment. *Nutrients*, *13*(2), 476. https://doi.org/10.3390/nu13020476

Von Ow, A., Waldvogel, T., & Nemecek, T. (2020). Environmental optimization of the Swiss population's diet using domestic production resources. *Journal of Cleaner Production, 248*, 119241. https://doi.org/10.1016/j.jclepro.2019.119241

Walker, C., Gibney, E. R., Mathers, J. C., & Hellweg, S. (2019). Comparing environmental and personal health impacts of individual food choices. *Science of The Total Environment, 685, 609–620.* https://doi.org/10.1016/j.scitotenv.2019.05.404

Walker, C., Pfister, S., & Hellweg, S. (2021). Methodology and optimization tool for a personalized low environmental impact and healthful diet specific to country and season. *Journal of Industrial Ecology*, *25*(5), 1147–1160. https://doi.org/10.1111/jiec.13131

Wallace, A., Martín, A., Bédard, A., Pitre, C., Lemieux, S., Simpson, J. R., Kirkpatrick, S. I., Hutchinson, J. M., Williams, T. E., Westaway, A. M., Lamarche, B., Day, M., Guenther, P. M., Jessri, M., L'Abbé, M. R., Louzada, M., Olstad, D. L., Prowse, R., Reedy, J., . . . Haines, J. (2023). Development of the Canadian Eating Practices Screener to assess eating practices based on 2019 Canada's Food Guide recommendations. *Applied Physiology, Nutrition, and Metabolism*, *48*(12), 907–918. https://doi.org/10.1139/apnm-2023-0081

Water. (2024, May 9). The Nutrition Source. https://nutritionsource.hsph.harvard.edu/water/

Weber, C. R., & Matthews, H. S. (2008). Food-Miles and the Relative Climate Impacts of Food Choices in the United States. *Environmental Science & Technology*, *42*(10), 3508–3513. https://doi.org/10.1021/es702969f

Wei, W., Larrey-Lassalle, P., Faure, T. M., Dumoulin, N., Roux, P., & Mathias, J. (2015). How to Conduct a Proper Sensitivity Analysis in Life Cycle Assessment: Taking into Account Correlations within LCI Data and Interactions within the LCA Calculation Model. *Environmental Science & Technology*, *49*(1), 377–385. https://doi.org/10.1021/es502128k

Werner, L. B., Flysjö, A., & Tholstrup, T. (2014). Greenhouse gas emissions of realistic dietary choices in Denmark: The carbon footprint and nutritional value of dairy products. *Food & Nutrition Research*, *58*(1), 20687. https://doi.org/10.3402/fnr.v58.20687

WHO. (2008, November). Fats and fatty acids in human nutrition. Report of an expert consultation. https://www.fao.org/fileadmin/user_upload/nutrition/docs/requirements/fatsandfattacidsreport.pdf

WHO. (2015). Guideline Sugars intake for adults and children [Guideline]. World Health Organization. https://iris.who.int/bitstream/handle/10665/149782/9789241549028_eng.pdf?sequence=1

WHO. (2019). *Sustainable Healthy Diets: Guiding Principles*. Food and Agriculture Organization of the United Nations.

WHO. (2023, July 17). Saturated fatty acid and trans-fatty acid intake for adults and children: WHO guideline. https://iris.who.int/bitstream/handle/10665/370419/9789240073630-eng.pdf?sequence=1

WHO. (n.d.). *Healthy diet*. World Health Organization. https://www.who.int/initiatives/behealthy/healthy-diet

Willett, W. C., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S. J., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. Á., De Vries, W., Sibanda, L. M., . . . Murray, C. J. L. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from

sustainable food systems. *The Lancet*, *393*(10170), 447–492. https://doi.org/10.1016/s0140-6736(18)31788-4

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., De Vries, W., Sibanda, L. M., . . . Murray, C. J. L. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet, 393(10170), 447–492. https://doi.org/10.1016/s0140-6736(18)31788-4

Wilson, N., Nghiem, N., Mhurchú, C. N., Eyles, H., Baker, M. G., & Blakely, T. (2013). Foods and Dietary Patterns that are Healthy, Low-Cost, and Environmentally sustainable: A case study of Optimization Modeling for New Zealand. PLOS ONE, 8(3), e59648. https://doi.org/10.1371/journal.pone.0059648

Wolk, A. (2017). Potential health hazards of eating red meat. *Journal of Internal Medicine*, *281*(2), 106–122. https://doi.org/10.1111/joim.12543

Young, H. (2022). Adherence to the EAT–Lancet diet: unintended consequences for the brain? *Nutrients*, *14*(20), 4254. https://doi.org/10.3390/nu14204254

Young, S. L. (2003). Life cycle assessment in Canada. *International Journal of Life Cycle Assessment*, *8*(6), 321–322. https://doi.org/10.1007/bf02978503

Zagmutt, F. J., Pouzou, J. G., & Costard, S. (2020). The EAT-Lancet commission's dietary composition may not prevent noncommunicable disease mortality. *The Journal of Nutrition*, *150*(5), 985–988. https://doi.org/10.1093/jn/nxaa020

Zhang, F., Laila, A., Leme, A. C. B., David, W. L., & Haines, J. (2022). Knowledge and perceptions of the 2019 Canada's Food Guide: a qualitative study with Canadian children. *Applied Physiology, Nutrition, and Metabolism*, *47*(11), 1096–1103. https://doi.org/10.1139/apnm-2022-0271

Zhao, H. J., Stennett, R., Kirkpatrick, S. I., & De Souza, R. J. (2023). Postsecondary students' knowledge of and adherence to the 2019 Canada's Food Guide: a cross-sectional pilot survey. *Canadian Journal of Dietetic Practice and Research*, *84*(4), 242–246. https://doi.org/10.3148/cjdpr-2023-008

Zhong, V. W., Van Horn, L., Greenland, P., Carnethon, M. R., Ning, H., Wilkins, J. W., Lloyd-Jones, D. M., & Allen, N. B. (2020). Associations of Processed Meat, Unprocessed Red Meat, Poultry, or Fish Intake With Incident Cardiovascular Disease and All-Cause Mortality. *JAMA Internal Medicine*, *180*(4), 503. https://doi.org/10.1001/jamainternmed.2019.6969

# Appendix A: Data

Table A - 1 Food Items from the Original 2015 CCHSN vs. Food Items chosen for Linear Optimization Model

| Food Category | Food Items in 2015 CCHSN | Food Items in LO model |
|---|---|---|
| Fruits | Apple | Apple |
| | Apple_juice | |
| | Banana | Banana |
| | Fruit_juice_other | |
| | Fruit_other | |
| | Grape | Grape |
| | Lemon | |
| | Lemon_juice | |
| | Mandarin | Mandarin |
| | Melon | Melon |
| | Olive | |
| | Orange | Orange |
| | Orange_juice | |
| | Peaches | Peaches |
| | Pear | Pear |
| | Pineapple | Pineapple |
| | Strawberry | Strawberry |
| Vegetables | Beans-green | Green beans |
| | Beet | Beet |
| | Broccoli | Broccoli |
| | Cabbage | Cabbage |
| | Carrot | Carrot |
| | Cauliflower | Cauliflower |
| | Celery | Celery |
| | Corn | Corn |
| | Cucumber | Cucumber |
| | Leafy greens | Leafy greens |
| | Lettuce | Lettuce |
| | Mushroom | Mushroom |
| | Onion | Onion |
| | Other_vegetables | |
| | Peas - green | Green peas |
| | Pepper | Pepper |
| | Potato | Potato |
| | Radish | Radish |
| | Spinach | Spinach |

| Food Category | Food Items in 2015 CCHSN | Food Items in LO model |
|---|---|---|
| | Squash | Squash |
| | Tomato | Tomato |
| | Tomato puree | Tomato puree |
| | Vegetable_juice | |
| | VEGETABLE_Soup_Gravy_Sauce | |
| Grains | GRAIN_Corn | |
| | GRAIN_other | |
| | GRAIN_rice | Rice |
| | GRAIN_wheat | |
| | GRAIN_Pasta | Pasta |
| | GRAIN_Pasta_dairy | |
| | BAKED_Bread_Bagel | Bread |
| | BAKED_granola_bar | |
| | BAKED_Leavening | |
| | BAKED_Cake_Cookie | |
| | CEREAL_Corn | |
| | CEREAL_Multigrain | |
| | CEREAL_Oat | Oat |
| | CEREAL_Rice | |
| | CEREAL_Wheat | |
| Meat | BEEF | Beef |
| | BEEF_soup_gravy | |
| | PORK | Pork |
| | SAUSAGE | |
| | SAUSAGE_Soup_Gravy_Sauce | |
| | POULTRY | Poultry |
| | POULTRY_soup_gravy | |
| | FISH | FISH |
| | FISH_can | FISH_can |
| | FISH_farmed | FISH_farmed |
| | FISH_Soup_Sauce | |
| | SEAFOOD | Seafood |
| Dairy | DAIRY_butter | |
| | DAIRY_cheese | Cheese |
| | DAIRY_cream | Cream |
| | DAIRY_egg | |
| | DAIRY_milk | Milk |
| | DAIRY_milk_drink | |
| | DAIRY_milk_powder | |
| | DAIRY_Soup_Sauce | |

| Food Category | Food Items in 2015 CCHSN | Food Items in LO model |
|---|---|---|
| | DAIRY_yogourt | Yogourt |
| Egg | | Egg |
| Milk Substitute | | Soy milk |
| Beans & Legumes | Beans | Beans |
| | Chickpea | Chickpea |
| | Soybean | |
| | Tofu | Tofu |
| Nuts & Seeds | Almond | Almond |
| | Cashew | Cashew |
| | Coconut | Coconut |
| | Nuts_other | |
| | Peanut | Peanut |
| | Seed_other | Seed_other |
| | Walnut | Walnut |
| Fats & Oils | FATS_beef | |
| | FATS_pork | |
| | FATS_poultry | |
| | FATS_OILS_margarine | |
| | FATS_OILS_salad | |
| | FATS_OILS_shortening | |
| | FATS_OILS_vegetable | Canola oil |
| | FATS_OILS_salad_dairy | Olive oil |
| Beverages | BEVERAGE_alcohol | |
| | BEVERAGE_Carbonated | |
| | BEVERAGE_coffee | Coffee |
| | BEVERAGE_Juice | |
| | BEVERAGE_plant | |
| | BEVERAGE_tea | Tea |
| | BEVERAGES_unknown | |
| | BEVERAGE_water | Water |
| Snacks | SNACKS_Corn_dairy | |
| | SNACKS | |
| | SNACKS_Corn | |
| | SNACKS_Potato | |
| Sweets | SWEET_Candies | |
| | SWEET_Dessert | |
| | SWEETS_Chocolate | |
| | SWEETS_Jams | |
| | SWEETS_Sugar | |
| | SWEET_Candies_dairy | |

| Food Category | Food Items in 2015 CCHSN | Food Items in LO model |
|---|---|---|
| | SWEET_Frozen_Dairy | |
| | SWEETS_Chocolate | |
| | SWEETS_Sugar_dairy | |
| | SWEETS_gelatin | |
| Spices | SPICES_HERBS | |

Table A - 2 Nutrient Constraint Calculations

| ***Category*** | ***Nutrients*** | ***Calculation (male and female > 18y)*** |
|---|---|---|
| **Nutrients to encourage** | Protein | AMDR: Total protein takes up 10-35% of total energy. 2000kcal*10%=200kcal, 2000kcal*35%=700kcal. Protein: 4kcal/g. 200kcal / 4kcal/g = 50g as lower bound, 700kcal / 4kcal/g = 175g as upper bound |
| | Fiber | AI for male = 30-38g, AI for female = 21-25g, mean = (30+38+21+25)/4 = 28.5g as lower bound |
| | Vitamin A | RDA/AI for male = 900 µg, RDA/AI for female = 700 µg. mean = (900+700)/2 = 800 µg as lower bound. UL = 3000 µg as upper bound |
| | Vitamin B12 | RDA/AI = 2.4 µg as lower bound |
| | Vitamin C | RDA/AI for male = 90 mg, RDA/AI for female = 75 mg. mean = (90+75)/2 = 82.5 mg as lower bound. UL = 2000 mg as upper bound |
| | Calcium | RDA/AI = 1000-1200 mg. mean = (1000+12000)/2 = 1100 mg as lower bound. UL = 2500 mg as upper bound |
| | Magnesium | RDA/AI for male = 400-420 mg, RDA/AI for female = 310-320 mg. mean = (400+420+310+320)/4 = 362.5 mg as lower bound |

| *Category* | *Nutrients* | *Calculation (male and female > 18y)* |
|---|---|---|
| | Iron | RDA/AI for male = 8 mg, RDA/AI for female = 8-18 mg. 8mg was chosen as the general lower bound but women who menstruate should take up to 18 mg iron. UL = 45 mg as upper bound |
| | Potassium | AI for male = 3400 mg, AI for female = 2600mg. mean = (3400+2600)/2 = 3000 mg as lower bound |
| **Nutrients to limit** | Sodium | 500mg was chosen as a low bound to support normal human body function. UL = 2300 mg as upper bound |
| | Added Sugar | WHO (2015) recommends reducing the intake of free sugars to less than 10% of total energy intake. 2000kcal*10% = 200kcal. Sugar: 4kcal/g. 200kcal / 4kcal/g = 50g as upper bound |
| | Saturated Fat | WHO (2023) recommends reducing saturated fatty acid intake to 10% of total energy intake. 2000kcal*10% = 200kcal. Fat: 9kcal/g. 200kcal / 9kcal/g ≈ 22g as upper bound |

Table A - 3 Food Items with Quantities for NNFB

| **Category** | **Product** | **Daily Purchased for 2000kcal (g)** |
|---|---|---|
| Vegetables | Green beans, frozen | 29.79 |
| | Broccoli, frozen, spears, boiled, drained | 14.03 |
| | Peas, green, frozen | 29.79 |
| | Pepper, sweet, green, fresh | 14.03 |
| | Lettuce, romaine, fresh | 24.95 |
| | Spinach, frozen | 14.03 |
| | Winter squash (e.g. pumpkin, butternut or acorn squash), fresh | 19.74 |
| | Carrots, fresh | 42.95 |
| | Sweet potato, fresh | 19.74 |

| Category | Product | Daily Purchased for 2000kcal (g) |
|---|---|---|
| | Potato, fresh (any type) | 34.91 |
| | Corn, frozen | 23.07 |
| | Cabbage, fresh | 30.03 |
| | Lettuce, iceberg, fresh | 27.45 |
| | Cucumber, fresh | 20.72 |
| | Celery, fresh | 21.73 |
| | Mushroom, fresh | 3.10 |
| | Onion, fresh | 21.73 |
| | Tomato, canned (no salt added, or low in sodium) | 40.88 |
| | Tomato, fresh | 12.42 |
| | Vegetables, mixed, frozen, boiled, drained | 29.02 |
| Fruits | Apple, fresh | 25.37 |
| | Banana, fresh | 46.02 |
| | Grapes, fresh | 6.21 |
| | Oranges, fresh | 25.37 |
| | Pear, canned (in water) | 12.42 |
| | Strawberries, frozen | 6.21 |
| | Peaches, canned (in water) | 12.42 |
| | Cantaloupe, melon, fresh | 12.42 |
| Milk Alternative | Fortified soy beverage, (unsweetened or original) | 98.33 |
| Beans & Legumes | Tofu, firm or extra firm | 11.15 |
| | Hummus | 3.10 |
| | Chickpeas, canned (no salt added, or low in sodium) | 7.03 |
| | Beans, kidney, canned (no salt added, or low in sodium) | 7.03 |
| | Beans, white, canned (no salt added, or low in sodium) | 8.00 |
| | Beans, black, canned (no salt added, or low in sodium) | 7.26 |
| | Lentils, dry | 8.55 |
| Nuts & Seeds | Sunflower seeds, unsalted | 6.02 |
| | Peanuts, dry roasted, unsalted | 5.95 |
| | Peanut butter, natural (nothing added) | 7.08 |
| Fish | Tuna, canned (no salt added) | 10.63 |
| | Salmon, pink, canned (no salt added, or low in sodium) | 4.35 |
| | Frozen white fish, fillets (sole, haddock, halibut, tilapia or perch) | 4.35 |
| Egg | Egg, chicken | 13.14 |
| Meat | Chicken, legs, fresh or frozen | 12.13 |
| | Turkey, all classes, ground | 7.96 |
| | Pork, loin, centre chop | 7.08 |
| | Beef, hip, inside (top) round roast, boneless, lean | 6.02 |

| Category | Product | Daily Purchased for 2000kcal (g) |
|---|---|---|
| Dairy | Mozzarella cheese, 16.5% B.F. | 6.21 |
| | Milk, partly skimmed, 2% M.F. | 98.33 |
| | Yogurt, plain, 1-2% | 35.17 |
| Grains | Brown rice | 75.07 |
| | Cereal, hot, oats, quick, prepared | 113.01 |
| | Grains, wheat flour, whole-grain, soft wheat | 15.83 |
| | Whole wheat pasta, spaghetti or macaroni | 82.94 |
| | Flat bread, whole-wheat, chapatti, roti or pita | 17.92 |
| | Dinner roll, whole wheat | 33.37 |
| | Toasted O's cereal, plain | 3.10 |
| | Shredded wheat cereal, plain | 3.10 |
| Fats & Oils | Vegetable oil | 4.87 |
| | Mayonnaise | 1.76 |
| | Margarine, tub, non-hydrogenated | 2.39 |