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Article

Socioeconomic and Environmental Prospects of the Food Industry

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Abstract: Food production systems and consumption patterns are significant contributors to the social, economic, and environmental impacts of the industry, which swap with changing population demographics. The life cycle assessment approach has been increasingly utilized to evaluate the agricultural and food processing systems to ensure reliable and evidence-based support for decision-making for both industry stakeholders and policymakers. This study discusses the key social, economic, and environmental impacts of various food processing sectors, especially greenhouse gas (GHG) emissions, land, water, and energy use. Impacts vary widely depending on the types of foods, their sources, and supply chains. The animal (excluding poultry) slaughtering, rendering, and processing category has the highest contributions in both socioeconomic and environmental impacts out of all food and beverage processing industries. The food industry touches transdisciplinary policy domains and is recognized as dynamic and complex. It is thus important to adopt an integrated approach involving stakeholders from all policy domains associated with food supply chains to ensure the sustainability of the food industry. A broader sustainability check must be adopted for any strategic change in the food industry to reduce the risks to its sustainability and avoid rebound effects on society.

Keywords: food processing industry; resources use; greenhouse gas emissions; social, economic, and environmental impacts; sustainability

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1. Introduction

Global greenhouse gas (GHG) emissions have increased remarkably due to human activities in different sectors. The world emits 50 billion tonnes of GHG each year (Ritchie, 2020). The food industry is one of the largest industrial sectors and thus, consumes a large number of resources, and emits a considerable amount of GHG, causing severe climate abnormalities. The food sector emits one-third of global anthropogenic GHGs (Crippa et al., 2021). Food production necessitates the utilization of diverse resources, with water and energy being crucial inputs throughout various stages of the food supply chain. These stages encompass activities such as crop and livestock production, food processing, manufacturing, as well as storage and distribution (Salmoral & Yan, 2018). One-fourth of the world's workforce is engaged in agriculture (Roser, 2023). The food demand and production processes are constantly changing with small and medium-scale industries decreasing in different jurisdictions. For example, small and medium-scale farms are decreasing in Canada while large-scale farms are increasing (Statistics Canada, 2017a; Statistics Canada, 2022a). The global food demand will continue to increase due to the increasing world population which is projected to be 9.8 billion in 2050 (Department of Economic and Social Affairs, n.d.). Hence, it is crucial to expand our understanding of the long-term social, economic, and environmental impacts of food production and research sustainable approaches to mitigate these impacts.

Currently, there is a growing body of literature that focuses on food systems and explores the connections between food and various dimensions of contemporary life. A wide range of indicators exist that encompass the economic, social, and environmental dimensions of the entire food system, including aspects such as sourcing raw materials, production, processing, packaging, distribution, and end-of-life considerations (Kucukvar et al., 2014). These indicators play a crucial role in achieving and improving the sustainability of food systems. Numerous studies have been conducted with a specific focus on environmental indicators within various food systems (Kucukvar et al., 2014; Egilmez et al., 2014) because of the growing concerns about the environmental sustainability of the food industry and the awareness of consumers. It is important to acknowledge that in addition to environmental indicators, the analysis of food system sustainability should also consider social and economic factors. However, societal, and economic prospects of the food industry along with environmental sustainability studies are scarce while the food demand and production are constantly changing in different jurisdictions with changing population demographics. This study provides a general overview of the current state of the Canadian food and beverage processing industry, discussing key social, economic, and environmental metrics of sustainability, and concluding with a summary of the most influential food and beverage processing sectors, having the highest contribution to the overall impacts of the food industry.

2. Methodology

This paper relied on a content evaluation where a comprehensive literature search was carried out using the Google Scholar web search engine, placing specific attention to more recent publications to gather the most up-to-date information to answer the research questions: environmental, economic, and societal prospects of the food industry. Social sustainability or impact, economic sustainability or impact, environmental sustainability or impact, food industry, consumption pattern, and life cycle impact assessment were used to find and collect relevant information that is compiled in this study. The literature collection process resulted in the identification of 87 articles (papers, reports, news, websites, etc.) related to this study. The articles were then read by the authorship team providing the environmental, economic, and societal insights of the food industry, and 75 articles were used in this study.

Environmental sustainability, based on natural sciences, primarily focuses on evaluating the overall effects of human activities on ecosystems. The most widely employed method for assessing these effects is the life cycle assessment (LCA). The LCA entails measuring and describing the inflow of resources (such as energy, land, and water) into the production system, as well as the emissions and impacts generated by the system. It is crucial to include the environmental impacts caused by these emissions across different spatial scales, while also considering the availability of resources at local, regional, and global levels. When conducting LCAs for environmental sustainability, it is important to base the scope on the function of production rather than organizational boundaries. Therefore, all inputs and outputs related to the production system should be taken into account, irrespective of economic ownership (Notarnicola et al., 2017). In this review, the literature on environmental sustainability was selected to include topics such as land and energy use, greenhouse gas emissions, eutrophication, pollution, food waste, and other environmental hazards.

Regarding economic sustainability, this aspect of sustainable development encompasses aspects such as job creation and income generation, aimed at supporting the population's financial well-being. However, the scientific community lacks a definitive consensus on the most effective methods for measuring economic sustainability. From a sustainability accounting perspective, the Global Reporting Initiative (GRI) reporting standards offer guidance on the factors to consider, including economic indicators like costs, revenues, profits, and investments (GRI, 2023). Essentially, the economic dimension of sustainable development emphasizes the growth of the economic system and the preservation of capital invested in businesses. A noteworthy differentiation can be made between weak and strong sustainability, which concerns natural and economic capital. Weak sustainability revolves around maintaining the combined sum of these two forms of capital, while strong sustainability focuses on preserving each type separately (Ayres et al., 2001). From an economic perspective, sustainability can also concentrate on the responsible utilization of natural resources within a defined economic system. This implies that sustainability is achieved when economic activities do not deplete natural resources. The economic concept of negative externalities proves useful in comprehending and accounting for all costs associated with production, including not only costs incurred by producers but also societal costs (Van den Bergh, 2010). In this review, we selected the literature which took into consideration economic indicators such as tax payments, profits, economic efficiency, costs, and investments in sustainability initiatives.

Social sustainability is a dimension of sustainability that has received less attention and lacks a precise definition (Vallance et al., 2011). It can be described as the capacity of a community to establish systems and frameworks that fulfill the needs of its members while ensuring the ability of future generations to maintain a thriving community (Davidson, 2009). However, there is no universally accepted definition of social sustainability, and it has been defined in various ways, often in relation to the other two dimensions of sustainability. One overarching definition proposes that social sustainability is the attainment of a life-enhancing state within communities, facilitated by a process that strives for such a condition (Hajirasouli & Kumarasuriyar, 2016). In this review, the concept of social sustainability discusses several indicators, including gender equality, health and safety rights, skill development, labor rights, and community resilience.

3. Food Processing Industry in Canada

Food and beverage processors engage in the conversion of raw food materials or substances into either finished product, ready for immediate consumption or use, or semi-finished products that serve as raw materials for subsequent manufacturing processes (Agriculture and Agri-Food Canada [AAFC], 2023a). In Canada, food and beverage processing industry plays a significant role in revenue generation. In 2019, the food and beverage processing industry accounted for 17% of the manufacturing sales, which represented 2% of the gross domestic product (GDP). The food and beverage industry is the second largest manufacturing industry in Canada, employing 290,000 people (AAFC, 2021).

Despite the size of the food processing industry in Canada, Canada still depends largely on the import of certain food from other countries. For instance, over 75% of the fresh vegetable demand in Canada is met through imports (International Trade Administration, 2022). Since the food is being transported over a longer distance to get to the consumers, this tends to increase its carbon footprint and contribute to food waste due to its limited shelf-life. Meat product manufacturing is the largest sector within the Canadian food and beverage processing industry, responsible for 25% of all manufacturing sales and generating $30 billion in 2019 (AAFC, 2021). It is the major food-producing sector in Quebec, Ontario, Manitoba, and Alberta. Dairy product manufacturing is the second largest sector within the industry generating $14.8 billion in sales in 2019 (AAFC, 2021).

3.1. Domestic Market and International Trade

The prosperity of the Canadian agricultural sector is greatly reliant on its ability to export agricultural products to other nations, and Canada is recognized as one of the world's major food exporters. In 2022, the total value of agriculture and food product exports from Canada, encompassing raw agricultural materials, fish and seafood, and processed foods, reached nearly $92.8 billion (AAFC, 2023a). Canada holds the fifth position globally as an exporter of agri-food and seafood, following the EU-27 block of countries, the United States, Brazil, and China. Canada exports to nearly 200 countries, based on 2022 data (AAFC, 2023a). Although Canada became the fifth food exporter on the earth, its agri-food and seafood imports reached $44.5 billion in the first 10 months of 2020 (AAFC, 2020). Additionally, it's worth to note that around 75% of the food supply in Canada comes from packaged and processed food items (L'AbbeLab, n.d.).

The United States stands as Canada's primary trading partner, responsible for approximately 60% of all agri-food and seafood exports and over half of the imports. Since 2012, China has consistently been Canada's second-largest export market for agri-food and seafood, with exports to China increasing by 75.8% during this period (AAFC, 2023a). While international markets are significant, the domestic market plays a critical role in the sector's performance. In 2022, Canadian households spent a total of $189.7 billion on food, beverages, tobacco, and cannabis products, positioning this expenditure category as the third-largest household expense, following transportation and shelter (AAFC, 2023a).

3.2. Sustainable Development of the Canadian Agri-Food System

Canada possesses several pivotal strengths that position it as a potential global leader in food production and processing: abundant land and water resources; access to international markets; capabilities to invest in research and development; high food quality and safety standards recognized globally; and strong commitment to environmental stewardship. The agriculture and agri-food sector in Canada exhibit substantial economic growth potential. Canada adopted a departmental sustainable strategy (AAFC no. 13134E) to ensure sustainable food (AAFC, 2022). Leveraging these key advantages can propel Canada to become a leader in sustainable food production and processing. Canada's strong reputation for environmental stewardship can drive higher demand and prices for local agricultural products. Capitalizing on these key opportunities is crucial to ensure that the sector remains competitive, sustainable, resilient, and prosperous well into the future. (AAFC, 2023a).

Food demand in Canada is increasing with changing population demographics. Canadian farmers and processors are assumed to be capable of meeting steadily increasing food demand; however, policy issues and policy controversies are prevailing with the increasing complexity of society. Food policy is considered to be a dynamic system (Kappelman & Sinha, 2021) where various stakeholders are engaged. It is not only dynamic but also multidimensional and highly complex, reaching several policy domains involving economic, environmental, societal, and cultural spheres (Barling et al., 2002). Canada has developed agricultural and food safety policies, and only later in 2017 the government has launched a multisectoral consultation for developing comprehensive food policy, extending beyond these two areas (Bancerz, 2018). Consequently, an integrated, and multidisciplinary approach is needed to improve the sustainability of food industries.

4. Impact Assessment of Food Industry

4.1. Social Sustainability

Key social indicators commonly mentioned in the literature in relation to the well-being of the food processing industry workers are quality of life, compensation of employees, labour rights, and worker's health and safety (Food and Agriculture Organization of the United Nations [FAO], 2014). The social and economic well-being of food industry workers are interconnected. One-fourth of the world's workforce is engaged in agriculture (Roser, 2023).

In 2022, Canada's agri-food system employed 2.3 million people, providing 1 in 9 jobs in Canada, along with $143.8 billion (around 7.0%) contribution to gross domestic product (GDP) (AAFC, 2023a). In the food and accommodation service industry, evening work is the most common, employing 21.8% of workers while regular evening hours workers are high among students, aged 15 to 24 of both the male and female groups (Statistics Canada, 2023). In April 2022, 918,000 people, aged 15 to 69, worked in a regular evening shift and were mostly part-time workers while only 3.3% of evening shift workers are full-time employees, and a similar trend was also found in the case of night-shift (Statistics Canada, 2023). In the United States, the food consumption categories have maintained a stable share in terms of income and employment, due to consistent demand, which can be translated to Canada, given the similarities in the economy (Kucukvar et al., 2019). Canada had 280,043 farms in 1991 which reached to 189,874 in 2021 while the average farm size changed from 598 acres to 809 acres (Statistics Canada, 2022a). The number of farm employees also changed from 327 to 257 thousand from 2008 to 2022 (Statista, 2023) while there were 293,925 farm operators in 2011 (Statistics Canada, 2017b) and 262,455 in 2021 (Statistics Canada, 2022b).

The U.S. food industry employed 22.1 million people in 2022 (U.S. Department of Agriculture [USDA], 2022). The shiftwork is prevalent in the food industry, nearly half of the workers were employed part-time in 2012 (Kucukvar et al., 2019). Most injuries that occur in the food industry are non-fatal and often arise from falls, slips, burnings, and lacerations. Young workers, who lack safety training and experience, tend to have higher rates of workplace injuries. Furthermore, a significant number of workers in this industry reported not receiving payment during their recovery period. A survey conducted among over 600 workers in the U.S. food industry revealed that only 21% of them received compensation during sick days. The authors noted that tobacco product manufacturing, breweries, and animal (excluding poultry) slaughtering, rendering, and processing accounted for 44% of the total tax revenue collected by the U.S. government (Kucukvar et al., 2019). When it comes to the compensation of employees and gender representation in the food industry, the major three categories were bread and bakery product manufacturing, animal (excluding poultry) slaughtering, rendering, and processing, and soft drink and ice manufacturing. These indicators contributed around 30 to 35 percent of the overall numbers. Injuries associated with animal (excluding poultry) slaughtering, rendering, and processing, as well as bread and bakery product manufacturing, and soft drink and ice manufacturing, accounted for 37% of the total injuries within the food industry.

4.2. Economic Sustainability

The primary economic indicators discussed in the literature for the food industry are internal and international investments, Gross Operating Surplus (GOS), Gross Domestic Product (GDP), imports, local economy and regional workforce (FAO, 2014). Canadian raw agricultural materials, fish and seafood, and processed foods exports reached $92.8 billion in 2022 (AAFC, 2023a) while agri-food and seafood imports were $44.5 billion in the first 10 months of 2020 (AAFC, 2020). In the first half of 2023, food and beverage sales increased by 8.4% and 7.3%, respectively compared to that of 2022 (Crosbie, 2023). The growth of the food and beverage industry is projected to rise to 11.6% by 2025 (BDC, 2022).

The U.S. agriculture, food, and related industries generated about US$1.264 trillion in 2021 (USDA, 2022). The food and beverage industry shared US$680.2 billion in 2022, an increase in compound annual growth rate (CAGR) of 3.6% compared to 2017 and it is expected to increase by 5% and reach US$869.1 billion by 2027 (AAFC, 2023b). Similarly, other food services such as chained food service franchises, the limited-service restaurants such as the eat-in channel are also expected to grow (AAFC, 2023b). Kucukvar et al. (2019) revealed that 34% of the GOS impact can be attributed to animal (excluding poultry) slaughtering, rendering, and processing, tobacco product manufacturing, and soft drink and ice manufacturing (Kucukvar et al., 2019). Moreover, in terms of the total investment indicator, the top three contributors were animal (excluding poultry) slaughtering, rendering, and processing, soft drink and ice manufacturing, and poultry processing, collectively accounting for 31% of the overall investment in the food sectors. Similarly, the aforementioned categories were identified as major contributors to the total intermediate value, representing 33% of the overall intermediate value for all food consumption categories.

4.3. Environmental Sustainability

The food industry is one of the largest industrial sectors and thus consumes large amounts of resources which emit GHGs and affect the environment. Every stage of the life cycle of food such as production, processing, manufacturing, packaging, distribution, storage and management of waste. Globally, food transport contributes 19% to total food system emissions (Li et al., 2022). Often, various impact categories of food industries are discussed; however, this study discusses the carbon footprint, energy consumption, water footprint, and land use.

4.3.1. Energy Consumption

Globally, 30% of the total energy is used in the food industry (UN-Water, n.d.). This is due to the dependency of the food industry on fossil fuel sources such as petroleum and natural gas. It was estimated that the food sector consumes 200 exajoule of energy annually, with 45% of the energy consumption used in the processing and distribution stages (Sims, 2011; FAO, 2017). Energy data reveals that instant coffee, milk powder, French fries, crisps, and bread rank among the food products with the highest energy requirements for production (Ladha-Sabur et al., 2019). The manufacturing processes for these items involve significant thermal energy consumption. It is thus crucial to explore alternate renewable energy sources to help mitigate GHG emissions and resource depletion.

In the meat and dairy processing sectors, energy and water usage have seen an increase due to elevated hygienic standards and more extensive cleaning requirements. Furthermore, meat products are often processed excessively to enhance consumer convenience, resulting in higher energy usage during manufacturing. In the United Kingdom (UK), more than 98% of all food is transported by road, with travel distances showing a recent upward trend. Tertiary distribution, which employs rigid vehicles, proves to be the most energy-intensive transportation method, while primary distribution at ambient temperature is the least energy-intensive. Refrigerated transportation, which demands more energy compared to stationary refrigeration systems, has also experienced an upswing in recent years (Ladha-Sabur et al. 2019). The authors noted that potato-based products had the highest energy consumption compared to other food categories (Figure 1) (Ladha-Sabur et al., 2019). It is worthy to note that energy consumption not only depends on the types of food but also contains different amounts of energy and food components (Roy et al., 2005, 2012a, 2022; Mekonnen et al., 2019). The energy consumption in the food sector can be reduced by adopting alternative food baskets as well as the processing intensity.

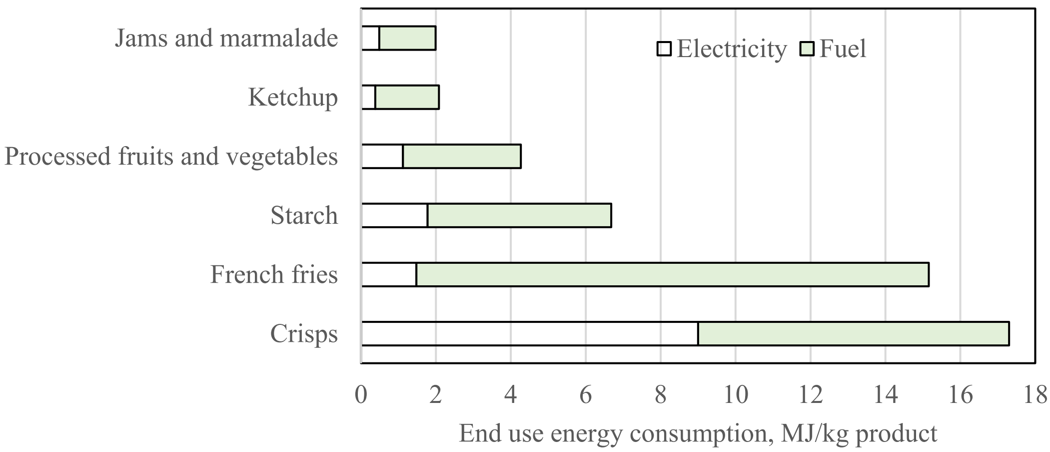

Figure 1. Energy consumption in fruits and vegetable processing. Adapted from "Mapping energy consumption in food manufacturing" by Ladha-Sabur et al., 2019, Trends in Food Science & Technology. Copyright 2019 by Elsevier Ltd.

In Canada, 92% of imported fruits and vegetables are transported more than 1,500 km, and 22% beyond 7,000 km (Kissinger, 2012). The first category of transport mostly includes truck shipments from the US, which contributed about 57% of all US - Canada trade in 2012 (Food Policy for Canada, n.d.). Road transport is the biggest contributor to total transport emissions; however, emissions per tonne-km for air freight and sea freight are the highest and the least, respectively (Food Policy for Canada, n.d.). Consequently, the improvement of local food supply as well as the selection of suitable transport methods would be helpful in reducing energy consumption in food transportation and improving the sustainability of the food sector.

Within the food industry, dairy processing is recognized as one of the sectors with the highest energy needs (Briam et al., 2015). Figure 2 demonstrates the energy consumption of different dairy products, with milk powder and whey powder having the highest energy consumption. This is likely due to the difference in their processing intensity (Adapted from Ladha-Sabur et al., 2019). When it comes to meat processing, in Ontario, sheep meat production process consumed 18.6–92.4 MJ/kg live weight (Bhatt & Abbassi, 2022). The United Nations also reported that meat production is more energy-intensive compared to other food categories (Climate Action, n.d.). Additionally, the study conducted by Tseng et al. (2019) concluded that there is higher energy usage and GHG emissions from the food industry compared to other industrial sectors and a recommendation was given to apply artificial intelligence and the concept of circular economy to help combat the challenges.

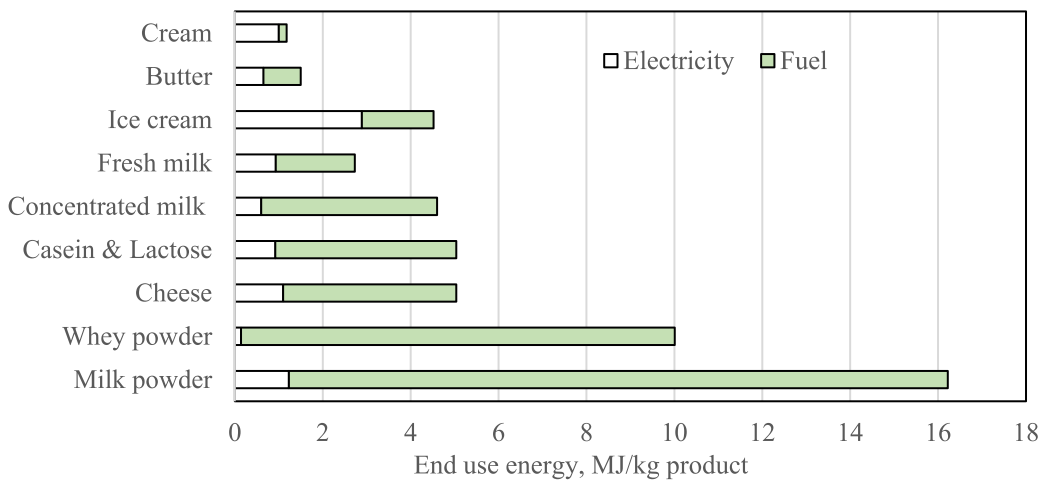

Figure 2. Energy consumption in dairy products processing. Adapted from "Mapping energy consumption in food manufacturing" by Ladha-Sabur et al., 2019, Trends in Food Science & Technology. Copyright 2019 by Elsevier Ltd.

4.3.2. Greenhouse Gas Emissions

Similar to energy consumption, GHG emissions also depend on the types of food, food production and processing, and distribution methods as well as sources of food (Blonk, 2017; Roy et al., 2022). For example, the environmental impacts of animal-based food are higher than plant-based food (Berardy et al., 2019; Heusala et al., 2020). The life cycle carbon footprint of oat- and faba protein is 50% and 80–90% lower than the dairy protein (Heusala et al., 2020). Figure 3 represents GHG emissions from protein which confirms that emissions depend on both the sources and types of food products (Adapted from Roy et al., 2022). Conversely, figure 4 represents GHG emissions from different food products (Adapted from Climate Action, n.d.). Meat has the highest emissions compared with other food categories, and nuts exhibit the lowest. However, this order of emissions magnitude may change if it is expressed in terms of food components such as protein or calories because these products contain different amounts of food components (Roy et al., 2022; Asadollahzadeh et al., 2018; Lee et al., 2020).

GHG emissions for grain crops also vary widely depending on the location of cultivation, type of crops, and methods of cultivation. For example, GHG emissions from rice production for conventional and organic cultivation in Malaysia were 0.46 and 0.14 kg-CO2 eq./kg rice, respectively (Harun et al., 2021) while in Bangladesh (Jimmy et al., 2017), Thailand (Thanawong et al., 2014) and Japan (Hokazono & Hayashi, 2012) it was 3.15, 2.97–5.55, and 1.46 kg-CO2 eq./kg, respectively. In Ontario, sheep production emits 8.4–18.6 kg CO2 eq./kg live weight (Bhatt & Abbassi, 2022). Similarly, emissions from meat production also vary widely. In Ontario, sheep production emits 8.4–18.6 kg CO2 eq./kg live weight (Bhatt & Abbassi, 2022) while in Japan, beef, pork, and chicken emitted about 34.3, 5.6, and 4.6 kg CO2 eq/kg-meat, respectively (Ogino et al., 2007; Roy et al., 2012a).

Emissions from a food basket (837436 kcal over a year; based on the Canadian food pyramid) in Ontario also widely varied depending on the dietary choices. For example, No Pork, Omnivorous, No red meat, and No beef dietary patterns emitted 3160, 2282, 1234, and 290 kg-CO2 eq., respectively, while Vegan and Vegetarian dietary patterns emitted 955 and 1015 kg-CO2 eq., respectively (Veeramani et al., 2017). The authors also noted that emissions from Omnivorous and Vegetarian dietary patterns widely vary among different jurisdictions. In addition, the projected population growth means there is a need to develop policies and techniques in the food production, distribution, and disposal of food to help combat the significant contribution to the carbon footprint.

Consequently, dietary patterns and recommended food pyramid for a healthy diet can play a crucial role in mitigating GHG emissions in different jurisdictions.

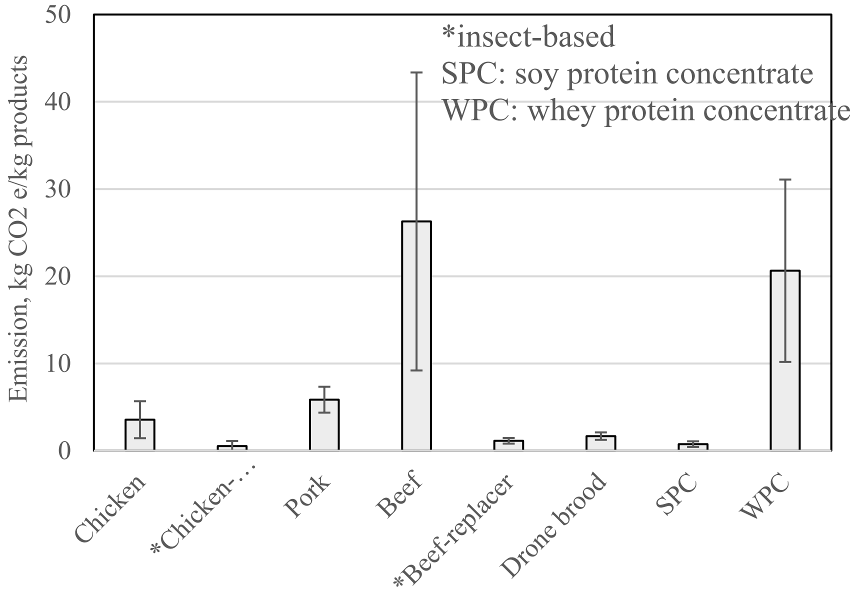

Figure 3. Emission of meat and meat substitute. Adapted from "Environmental Aspects of Plant Protein Foods" by Roy et al., 2022, Springer Cham. Copyright 2022 by Springer Nature.

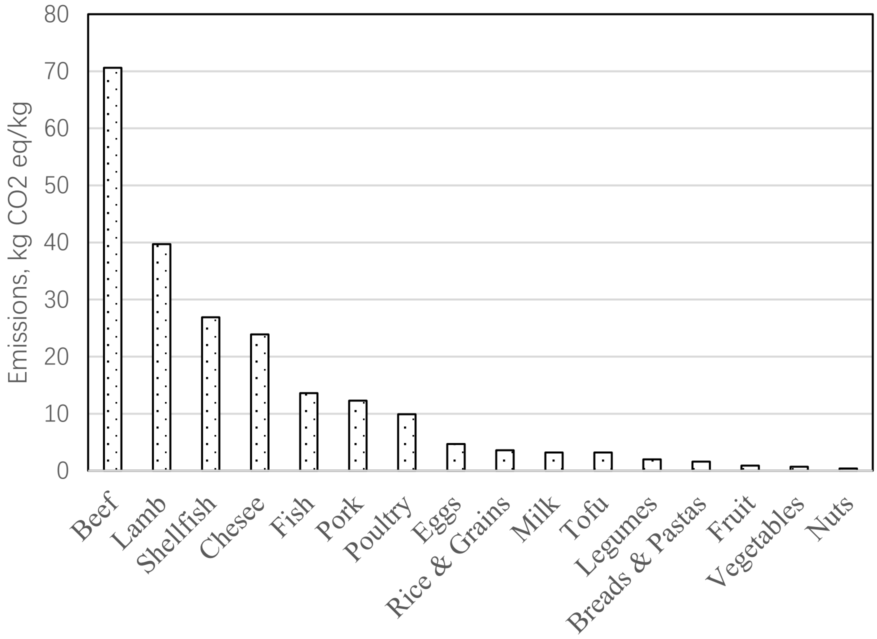

Figure 4. Kilograms of greenhouse gas emissions per kilogram of food. Adapted from "Food and Climate Change: Healthy diets for a healthier planet" by Climate Action. Copyright by United Nations.

4.3.3. Water Use

The food industry is largely dependent on the use of large amounts of fresh water. Water footprint represents the total amount of water that is used in the food industry. Agriculture accounts for the largest share of freshwater consumption globally and is a leading cause of freshwater eutrophication. The food industry also generates a lot of wastewaters that ends up polluting water sources, if not properly managed. To put this in perspective, 70% of the world's freshwater is used in food production and approximately, 78% of the world's eutrophication is caused by food production (Ritchie et al., 2022). The water footprint also widely varies depending on the sources of food, types of food, and their processing intensity. For example, for soy protein isolate, water use was noted to be 38.95 m3/kg protein-isolate (Berardy et al., 2015) while it was 0.64 m3/kg for milk and 16.67 m3/kg for beef (Mekonnen et al., 2019).

Water footprint for different crop production also widely varies depending on the locations, cultivation methods, and types of crops (Kalvani et al., 2019; Harun et al., 2021; Yu et al., 2022). In the Teheran province of Iran, the water footprint for pistachio, cotton, walnut, almond, and wheat was 11.11 m3/kg, 4.70 m3/kg, 3.93 m3/kg, 3.22 m3/kg, and 1.82 m3/kg, respectively (Kalvani et al., 2019) while it was noted to be about 0.8 m3/kg for maize, 1.4 m3/kg rice, 1.9 m3/kg wheat, respectively, in China (Yu et al., 2022) and 0.06–0.27 m3/kg for sheep production in Ontario (Bhatt & Abbassi, 2022). In Malaysia, a cradle-to-gate analysis of conventional and organic rice cultivation revealed that the water footprint was 0.098 m3/kg and 0.029 m3/kg for conventional and organic rice cultivation, respectively (Harun et al., 2021). It is also noted that water is required for food production or cultivation; however, less than 50% of the water applied through irrigation is used by crops (Sims, 2011). Different studies have shown that animal food products consume more water compared to crops' equivalent nutritional value. An example of this is the water consumption in beef production which is 20 times more than for cereals and starch roots (Vanham et al., 2013).

4.3.4. Land Use

Agriculture remains a significant source of livelihood for 40% of the global population and contributes around 30% to the GDP of low-income countries. Moreover, it plays a crucial role in providing sustenance, fiber, biofuels, and various other products to support the current global population (Ramankutty et al., 2018). Similar to GHG emissions, land use also widely varies depending on the sources, categories, and processing intensity of food. For example, land use for plant-based proteins was 1.7–13.3 m2/kg of protein (Smetana et al., 2019; Heusala et al., 2020). Conversely, animal-based proteins required 4.95–210.0 m2/kg of protein (Gésan-Guiziou et al., 2019; Thrane et al., 2017; Ulmer et al., 2020). Land use was the highest for beef-based protein followed by chicken, and pork (Thrane et al., 2017; Ulmer et al., 2020). Per capita, cultivable land is decreasing with the increasing population growth and industrial development. Globally, per capita cropland decreased from 0.45 ha in 1961 to 0.21 ha in 2016 (FAO, 2020). Agricultural land decreased by 30% since 1990 and reached 0.6 ha/capita in 2019 (FAO, 2021). Deforestation and removal of other natural vegetation contribute to climate change and the loss of biodiversity. Striking a balance between the environmental impact of agriculture and the imperative to sustainably feed current and future populations poses a substantial challenge. Thus, efforts are needed to ensure the efficient use of the available land to improve the sustainability of food systems.

5. Discussion

The growing concerns about climate change and the sustainability of existing food systems, the food industry is facing increasing pressure for sustainability and the health and safety of consumers. Although food consumption patterns are dependent on accessibility, availability, health concerns, and cultural and regional preferences, food demand is rapidly changing with international trade and changing population demographics in different jurisdictions. International trade enables year-round supplies of a variety of food which benefits consumers; however, imported food often exhibits a greater food carbon footprint as well as it is prone to food safety and quality because imported foods need to go through strict quarantine activities which also results in the shorter shelf-life due to long distance transportation leading to higher food loss, especially in the case of fresh fruits and vegetables. Canada loses or wastes 58% of all food supply annually (Nikkel et al., 2019) which affects the environmental sustainability of her food industry. Although food miles are often recognized as one of the environmental inefficiencies, it would not be the only determinant since agricultural production widely varies in different jurisdictions on the earth.

The food industry is recognized as a dynamic and multidimensional system, that touches several policy domains (economic, environmental, societal, and cultural spheres) (Barling et al., 2002; Kappelman & Sinha, 2021). Thus, the sustainability of the food industry also depends on multiple policy domains such as agriculture, food supply and demand, food pyramid, food self-sufficiency, food consumption patterns, etc. An empirical analysis of social, economic, and environmental impacts of food consumption categories (29 consumption categories were considered for evaluating direct and indirect impacts) in the USA revealed that supply chains are responsible for 80% of socioeconomic and environmental impacts such as gross operating surplus and imports, where animal slaughtering, rendering and processing emerged as the most dominant sector (Kucukvar et al., 2019).

Figure 5 shows the environmental, economic, and social heat map of different food consumption categories (Adapted from Kucukvar et al., 2019). The heat map analysis shows that the top three food consumption categories were animal slaughtering, rendering and processing (except poultry), soft drink and ice manufacturing, and bread and bakery product manufacturing. Animal slaughtering, rendering and processing, bread and bakery product manufacturing, and soft drink and ice manufacturing contributed 37% injuries of in overall food categories while animal slaughtering, rendering, and processing category contributed 30% GHGs all over the food consumption categories. This study revealed several weaknesses associated with the top three food consumption categories. In order to promote sustainable development and continuous improvement, it is recommended to establish and adopt policy implications. Policymakers should prioritize measures aimed at reducing injury rates in the animal and soft drink manufacturing and processing industries. Implementing rigorous safety and health regulations and standards, both locally and internationally, can effectively reduce human health impacts. Additionally, the state standards should enforce the use of the latest available technologies that prioritize maximum energy efficiency.

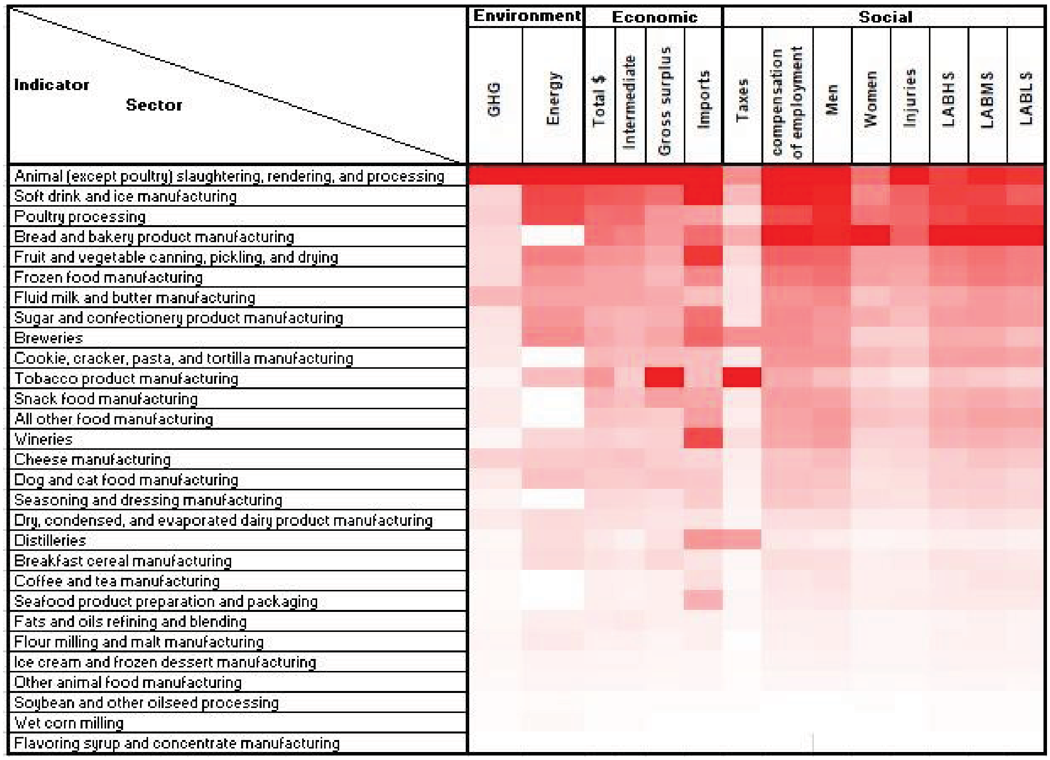

Figure 5. Heat map diagram illustrating the total impacts per food consumption category and indicator, based on the overall impact analysis (white represents the lowest and red represents the highest). Adapted from "Exploring the social, economic and environmental footprint of food consumption: A supply chain-linked sustainability assessment" by Kucukva et al., 2019, Institute of Electrical and Electronics Engineers [IEEE]. Copyright 2019 by IEEE.

The dwindling agricultural land area and agricultural workforce along with the climate change impact may also hinder the sustainability of the food industry. As the food industry touches multiple policy domains and a recognized dynamic system, multidisciplinary and integrated approaches would play a crucial role in the new food policy development. The integrated approach should include stakeholders at both the national and international levels while emphasizing the safety, quality, markets, and sustainability of food products that require contributions from all stakeholders. An updated food policy, standards, and regulations on land use, sourcing of food, and easy access to desired quality food would be required which not only reduces food waste but also lead to the sustainability of the food industry. In addition, the availability of environmental information may enable environmentally conscious consumers to select more environmentally friendly products and thus contribute towards the sustainability of the food industry. A broader sustainability check must be adopted for implementing any updated food policy, food standard, and production and consumption strategies in order to reduce risks to the sustainability of the food industry and avoid any rebound effects on society.

6. Conclusions

Growing concerns about climate change and the sustainability of the food industry led to the initiation of various activities to enhance the food supply, reduce food waste, and improve the sustainability of the food industry. Facilitating a shift towards more sustainable production and consumption patterns calls for the adoption of a comprehensive approach, where life cycle thinking is widely recognized as a crucial concept to support this objective. While the number of empirical publications on the topic may not be extensive, it has grown significantly in recent years, primarily driven by the concerns of consumers regarding food sustainability. Food demand and production are constantly changing with increasing and changing population demographics in different jurisdictions and the need to engage more workforce. The food industry touches transdisciplinary domains and thus integrated and multisectoral approach engaging all stakeholders would play a crucial role in a sustainable food policy which may enhance food self-sufficiency and security, reduce food waste, ensure desired quality food products, encourage and satisfy the associated workforce, and attract more investment to improve the sustainability of the food industry.

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References

Agriculture and Agri-Food Canada. (2023a). *Overview of Canada's agriculture and agri-food sector.* Government of Canada. https://agriculture.canada.ca/en/sector/overview

Agriculture and Agri-Food Canada. (2023b). *Foodservice Profile – United States.* Government of Canada. Retrieved December 7, 2023, from https://agriculture.canada.ca/en/international-trade/market-intelligence/reports/foodservice-profile-united-states

Agriculture and Agri-Food Canada. (2022). *2021–2022 Departmental Sustainable Development Strategy.* Government of Canada. Retrieved December 5, 2023, from https://agriculture.canada.ca/en/department/initiatives/federal-sustainable-development-strategy/2021-22-departmental

Agriculture and Agri-Food Canada. (2021). *Overview of the food and beverage processing industry.* Government of Canada. Retrieved October 9, 2023, from https://agriculture.canada.ca/en/sector/food-processing-industry/overview-food-beverage

Agriculture and Agri-Food Canada. (2020). *Sector Trend Analysis – Fish and seafood trends in Canada*. Government of Canada. https://agriculture.canada.ca/en/international-trade/market-intelligence/reports/sector-trend-analysis-fish-and-seafood-trends-canada

Asadollahzadeh, M., Ghasemian, A., Saraeian, A., Resalati, H., & Taherzadeh, M. J. (2018). Production of fungal biomass protein by filamentous fungi cultivation on liquid waste streams from pulping process. *BioResources*, *13*(3), 5013–5031. https://doi.org/10.15376/biores.13.3.5013-5031

Ayres, R., Van den Berrgh, J., & Gowdy, J. (2001). Strong versus weak sustainability: Economics, natural sciences, and consilience. *Environmental Ethics*, *23*(2), 155–168. https://doi.org/10.5840/enviroethics200123225

Bancerz, M. (2018). Contested Sustainability Discourses in the Agrifood System. In D. H. Constance, J. Konefal & M. Hatanaka (Eds.), *Understanding the challenge of problem definition in multistakeholder initiatives* (pp. 224–240). Routledge. https://doi.org/10.4324/9781315161297

Barling, D., Lang, T., & Caraher, M. (2002). Joined-up food policy? The trials of governance, public policy and the food system. *Social Policy & Administration*, *36*(6), 556–574. https://doi.org/10.1111/1467-9515.t01-1-00304

BDC. (2022). *Canadian Food and Beverage Industry 2022 Outlook*. https://www.bdc.ca/globalassets/digizuite/37406-2022-report-food-and-beverage-industry.pdf

Berardy, A., Costello, C., & Seager, T. P. (2015). Life cycle assessment of soy protein isolate. *Proceedings of the International Symposium on Sustainable Systems and Technologies*, *3*, 18–20. https://www.researchgate.net/publication/308885062_Life_Cycle_Assessment_of_Soy_Protein_Isolate

Berardy, A., Johnston, C. S., Plukis, A., Vizcaino, M., & Wharton, C. (2019). Integrating protein quality and quantity with environmental impacts in life cycle assessment. *Sustainability*, *11*(10), 2747. https://doi.org/10.3390/su11102747

Bhatt, A., & Abbassi, B. (2022). Life cycle impacts of sheep sector in Ontario, Canada. *The International Journey of Life Cycle Assess*, *27*, 1283–1298. https://doi.org/10.1007/s11367-022-02105-1

Blonk. (2017, December 14). *Revealing the environmental impact of plant proteins*. https://blonksustainability.nl/news/revealing-the-environmental-impact-of-plant-proteins

Briam, R., Walker, M. E., & Masanet, E. (2015). A comparison of product-based energy intensity metrics for cheese and whey processing. *Journal of Food Engineering*, *151*, 25–33. https://doi.org/10.1016/j.jfoodeng.2014.11.011

Climate Action. (n.d.). *Food and Climate Change: Healthy diets for a healthier planet*. United Nations. https://www.un.org/en/climatechange/science/climate-issues/food

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*, 198–209. https://doi.org/10.1038/s43016-021-00225-9

Crosbie, G. (2023). *2023 Food and Beverage Report: Mid-year update*. Farm Credit Canada. https://www.fcc-fac.ca/en/knowledge/economics/2023-food-beverage-mid-year-report

Davidson, M. (2009). Social sustainability: A potential for politics. *Local Environment*. *14*(7), 607–619. https://doi.org/10.1080/13549830903089291

Department of Economic and Social Affairs. (n.d.). *World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100*. United Nations. https://www.un.org/en/desa/world-population-projected-reach-98-billion-2050-and-112-billion-2100

Egilmez, G., Kucukvar, M., Tatari, O., & Bhutta, M. K. S. (2014). Supply chain sustainability assessment of the US food manufacturing sectors:

A life cycle-based frontier approach. *Resources, Conservation and Recycling*, *82*, 8–20. https://doi.org/10.1016/j.resconrec.2013.10.008
Food and Agriculture Organization of the United Nations. (2014). Sustainability assessment of food and agriculture systems (SAFA). UN Guidelines.
Food and Agriculture Organization of the United Nations. (2021). *Land use statistics and indicators: Global, regional and country trends 1990–2019*. https://www.fao.org/3/cb6033en/cb6033en.pdf
Food and Agriculture Organization of the United Nations. (2020, May 7). *Land use in agriculture by the numbers*. https://www.fao.org/sustainability/news/detail/en/c/1274219
Food and Agriculture Organization of the United Nations. (2017). *The future of food and agriculture: Trends and challenges*. http://www.fao.org/3/a-i6583e.pdf
Food Policy for Canada. (n.d.). *Challenges of food transport in Canada*. York University. https://foodpolicyforcanada.info.yorku.ca/goals/goal-5/sustainable-transportation/challenges-transport/
Gésan-Guiziou, G., Sobańtka, A. P., Omont, S., Froelich, D., Rabiller-Baudry, M., Thueux, F., Beudon, D., Tregret, L., Buson, C., & Auffret, D. (2019). Life Cycle Assessment of a milk protein fractionation process: Contribution of the production and the cleaning stages at unit process level. *Separation and Purification Technology*, *224*, 591–610. https://doi.org/10.1016/j.seppur.2019.05.008
Global Reporting Initiative. (2023). *Global Reporting Initiative (GRI) Response: Proposed International Standard on Sustainability Assurance 5000 General Requirements for Sustainability Assurance Engagements*. https://www.globalreporting.org/standards/standards-development/universal-standards/
Hajirasouli, A. H., & Kumarasuriyar, A. (2016). The social dimention of sustainability: Towards some definitions and analysis. *Journal of Social Science for Policy Implications*, *4*(2), 23–34. https://eprints.qut.edu.au/114108/
Ritchie, H., Rosado, P., & Roser, M. (2022). *Environmental Impacts of Food Production*. Our World in Data. https://ourworldindata.org/environmental-impacts-of-food
Harun, S. N., Hanafiah, M. M., & Aziz, N. I. H. A. (2021). An LCA-based environmental performance of rice production for developing a sustainable agri-food system in Malaysia. *Environmental Management*, *67*, 146–161. https://doi.org/10.1007/s00267-020-01365-7
Heusala, H., Sinkko, T., Sözer, N., Hytönen, E., Mogensen, L., & Knudsen, M. T. (2020). Carbon footprint and land use of oat and faba bean protein concentrates using a life cycle assessment approach. *Journal of Cleaner Production*, *242*, 118376. https://doi.org/10.1016/j.jclepro.2019.118376
Hokazono, S., & Hayashi, K. (2012). Variability in environmental impacts during conversion from conventional to organic farming: A comparison among three rice production systems in Japan. *Journal of Cleaner Production*, *28*, 101–112. https://doi.org/10.1016/j.jclepro.2011.12.005
International Trade Administration. (2022). *Canada-Country Commercial Guide: Agricultural Sector.* Retrieved Octorber 10, 2022, from https://www.trade.gov/knowledge-product/canada-agricultural-sector
Jimmy, A. N., Khan, N. A., Hossain, M. N., & Sujauddin, M. (2017). Evaluation of the environmental impacts of rice paddy production using life cycle assessment: Case study in Bangladesh. *Modeling Earth Systems and Environment*, *3*, 1691–1705. https://doi.org/10.1007/s40808-017-0368-y
Kalvani, S. R., Sharaai, A. H., Abd Manaf, L., & Hamidian, A. H. (2019). Water footprint of crop production in Tehran Province. *Planning Malaysia*, *17*(2), 123–132. https://doi.org/10.21837/pm.v17i10.634
Kappelman, A. C., & Sinha, A. K. (2021). Optimal control in dynamic food supply chains using big data. *Computers & Operations Research*, *126*, 105117. https://doi.org/10.1016/j.cor.2020.105117
Kissinger, M. (2012). International trade related food miles—The case of Canada. *Food Policy*, *37*(2), 171–178. https://doi.org/10.1016/j.foodpol.2012.01.002
Kucukvar, M., Egilmez, G., & Tatari, O. (2014). Evaluating environmental impacts of alternative construction waste management approaches using supply-chain-linked life-cycle analysis. *Waste Management & Research*, *32*(6), 500–508. https://doi.org/10.1177/0734242X14536457
Kucukvar, M., Ismaen, R., Onat, N. C., Al-Hajri, A., Al-Yafay, H., & Al-Darwish, A. (2019). 2019 IEEE 6th International Conference on Industrial Engineering and Applications (ICIEA). In *Exploring the social, economic and environmental footprint of food consumption: A supply chain-linked sustainability assessment*. Institute of Electrical and Electronics Engineers (pp. 733–742). https://doi.org/10.1109/IEA.2019.8715234
L'AbbeLab. (n.d.). *The Canadian Food Supply*. https://labbelab.utoronto.ca/projects/the-canadian-food-supply/
Ladha-Sabur, A., Bakalis, S., Fryer, P. J., & Lopez-Quiroga, E. (2019). Mapping energy consumption in food manufacturing. *Trends in Food Science & Technology*, *86*, 270–280. https://doi.org/10.1016/j.tifs.2019.02.034
Lee, H. J., Yong, H. I., Kim, M., Choi, Y. S., & Jo, C. (2020). Status of meat alternatives and their potential role in the future meat market—A review. *Asian-Australasian Journal of Animal Sciences*, *33*(10), 1533–1543. https://www.animbiosci.org/upload/pdf/ajas-20-0419.pdf
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*, 445–453. https://doi.org/10.1038/s43016-022-00531-w
Mekonnen, M. M., Neale, C. M. U., Ray, C., Erickson, G. E., & Hoekstra, A. Y. (2019). Water productivity in meat and milk production in the US from 1960 to 2016. *Environment International*, *132*, 105084. https://doi.org/10.1016/j.envint.2019.105084
Nikkel, L., Gooch, M., & Bucknell, D. (2019). *The avoidable crisis of food waste: The roadmap*. Second Harvest. https://secondharvest.ca/getmedia/57cc6c6c-bfb6-4392-bbf5-c7f46f1a9e89/The-Avoidable-Crisis-of-Food-Waste-Roadmap.pdf
Notarnicola, B., Sala, S., Anton, A., McLaren, S. J., Saouter, E., & Sonesson, U. (2017). The role of life cycle assessment in supporting sustainable agri-food systems: A review of the challenges. *Journal of Cleaner Production*, *140*(part 2), 399–409. https://doi.org/10.1016/j.jclepro.2016.06.071
Ogino, A., Orito, H., Shimada, K., & Hirooka, H. (2007). Evaluating environmental impacts of the Japanese beef cow-calf system by the life cycle assessment method. *Animal Science Journal*, *78*(4), 424–432. https://doi.org/10.1111/j.1740-0929.2007.00457.x
Ramankutty, N., Mehrabi, Z., Waha, K., Jarvis, L., Kremen, C., Herrero, M., & Rieseberg, L. H. (2018). Trends in global agricultural land use: Implications for environmental health and food security. *Annual Review of Plant Biology*, *69*, 789–815. https://doi.org/10.1146/annurev-arplant-042817-040256
Ritchie, H. (2020). *Sector by sector: where do global greenhouse gas emissions come from?* Our World in Data. https://ourworldindata.org/ghg-emissions-by-sector
Roser, M. (2023). *Employment in agriculture*. Our World in Data. https://ourworldindata.org/employment-in-agriculture

Roy, P., Orikasa, T., Thammawong, M., Nakamura, N., Xu, Q., & Shiina, T. (2012a). Life cycle of meats: An opportunity to abate the greenhouse gas emission from meat industry in Japan. *Journal of Environmental Management*, *93*(1), 218–224. https://doi.org/10.1016/j.jenvman.2011.09.017
Roy, P., Orikiasa, T., & Shiina, T. (2022). Plant Protein Foods. In A. Manickavasagan, L. Lim & A. Ali (Eds.), *Environmental Aspects of Plant Protein Foods* (pp. 467–484). Springer Cham. https://doi.org/10.1007/978-3-030-91206-2_16
Roy, P., Shimizu, N., & Kimura, T. (2005). Life cycle inventory analysis of rice produced by local processes. *Journal of the Japanese Society of Agricultural Machinery*, *67*(1), 61–67. https://doi.org/10.11357/jsam1937.67.61
Salmoral, G., & Yan, X. (2018). Food-energy-water nexus: A life cycle analysis on virtual water and embodied energy in food consumption in the Tamar catchment, UK. *Resources, Conservation and Recycling*, *133*, 320–330. https://doi.org/10.1016/j.resconrec.2018.01.018
Sims, R. (2011). *Energy-smart food for people and climate.* Food and Agriculture Organization of the United Nations. https://www.fao.org/climatechange/29891-083e131f59a2ff4b7552651a87043dbe1.pdf
Smetana, S., Schmitt, E., & Mathys, A. (2019). Sustainable use of Hermetia illucens insect biomass for feed and food: Attributional and consequential life cycle assessment. *Resources, Conservation and Recycling*, *144*, 285–296. https://doi.org/10.1016/j.resconrec.2019.01.042
Statistics Canada. (2023). *Quality of Employment in Canada: Evening work, 2022*. https://www150.statcan.gc.ca/n1/pub/14-28-0001/2023001/article/00006-eng.htm
Statistics Canada. (2022a). *Land use, Census of Agriculture historical data*. https://doi.org/10.25318/3210015301-eng
Statistics Canada. (2022b). *Characteristics of farm operators: Farm work and other paid work, Census of Agriculture, 2021*. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210038201
Statistics Canada. (2017a). *Canadian agriculture: evolution and innovation*. https://www150.statcan.gc.ca/n1/en/pub/11-631-x/11-631-x2017006-eng.pdf?st=06Ixr_vK
Statistics Canada. (2017b). *Characteristics of farm operators: Other paid work, Census of Agriculture, 2011 and 2016*. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210044501
Statista. (2023). *Number of employees of the agriculture industry in Canada from 2008 to 2022*. https://www.statista.com/statistics/454083/number-of-employees-of-the-agriculture-industry-canada/
Thanawong, K., Perret, S. R., & Basset-Mens, C. (2014). Eco-efficiency of paddy rice production in Northeastern Thailand: A comparison of rain-fed and irrigated cropping systems. *Journal of Cleaner Production*, *73*, 204–217. https://doi.org/10.1016/j.jclepro.2013.12.067
Thrane, M., Paulsen, P. V., Orcutt, M. W., & Krieger, T. M. (2017). Sustainable Protein Sources. In S. R. Nadathur, J. P. D. Wanasundara & L. Scanlin (Eds.), *Soy protein: Impacts, production, and applications* (pp. 23–45). Academic Press. https://doi.org/10.1016/B978-0-12-802778-3.00002-0
Tseng, M. L., Chiu, A. S. F., Chien, C. F., & Tan, R. R. (2019). Pathways and barriers to circularity in food systems. *Resources, Conservation and Recycling*, *143*, 236–237. https://doi.org/10.1016/j.resconrec.2019.01.015
Ulmer, M., Smetana, S., & Heinz, V. (2020). Utilizing honeybee drone brood as a protein source for food products: Life cycle assessment of apiculture in Germany. *Resources, Conservation and Recycling*, *154*, 104576. https://doi.org/10.1016/j.resconrec.2019.104576
UN-Water, (n.d.). *Water, Food and Energy*. United Nations. https://www.unwater.org/water-facts/water-food-and-energy
U.S. Department of Agriculture. (2022). *Ag and Food Sectors and the Economy*. Retrieved December 7, 2023, from https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy/
Vallance, S., Perkins, H. C., & Dixon, J. E. (2011). What is social sustainability? A clarification of concepts. *Geoforum*, *42*(3), 342–348. https://doi.org/10.1016/j.geoforum.2011.01.002
Van den Bergh, J. C. J. M. (2010). Externality or sustainability economics? *Ecological Economics*, *69*(11), 2047–2052. https://doi.org/10.1016/j.ecolecon.2010.02.009
Vanham, D., Mekonnen, M. M., & Hoekstra, A. Y. (2013). The water footprint of the EU for different diets. *Ecological Indicators*, *32*, 1–8. https://www.waterfootprint.org/resources/Vanham-et-al-2013_2.pdf
Veeramani, A., Dias, G. M., & 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
Yu, A., Cai, E., Yang, M., & Li, Z. (2022). An analysis of water use efficiency of staple grain productions in China: Based on the crop water footprints at provincial level. *Sustainability*, *14*(11), 6682. https://doi.org/10.3390/su14116682