CONSIDERATIONS OF THE CARBON FOOTPRINT OF IMPORTED AND DOMESTIC LETTUCE FOR CANADIAN RETAILERS

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INTRODUCTION & BACKGROUND

The objective of the 2015 Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) is to hold the rise in global average temperatures by 2100 to 'well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels'. Over 100 countries – including Canada – voluntarily pledged to reduce their agricultural greenhouse gas (GHG) emissions for the Agreement in their statement to the UNFCCC (Richards et al., 2016). In the Canadian GHG emission summary for 2017, 60 Mt of CO_2 eq were attributed to the agricultural sector out of a total 716 Mt of CO_2 eq emitted from all sources. The agricultural sector in Canada can have an impact on managing national GHG emissions, as it is currently accountable for 8% of the national emissions in this report (Environment and Climate Change Canada, 2019).

Canadian Perspective on Lettuce Production:

- 84,902 metric tonnes of field leaf and head lettuce. According Statistic Canada (2016), 80% of the 3375 hectares of field lettuce were produced in Quebec
- 6,081 metric tonnes of greenhouse lettuce In 2018, Quebec produced 62% of the greenhouse lettuce, or 3 516 486 kg of fresh lettuce (L.-A. Gagné, personal communication, February 4, 2020)
- Canada has the largest concentration of greenhouses in North America, and this production method is the fastest growing part of the agricultural sector in Canada
- Lettuce is the most consumed fresh vegetable, estimated at 8.4-9.6 kg per person annually (MAPAQ, 2018; MAPAQ, 2017).
- 18,038 metric tons of fresh lettuce were exported in 2015
- In 2017, 191,914 metric tons of lettuce were imported to Canada making it the most imported produce by weight, primarily sourced from the U.S. ("Statistical Overview of the Canadian Vegetable Industry", 2017).

This study focuses on retailers that supply food to Toronto and its surrounding suburbs, the Greater Toronto Area (GTA). Census metropolitan areas (CMAs) make up 71.7% of the Canadian population, and Toronto is the largest CMA in Canada with 2.3M residents with a growth rate of 2% (Statistics Canada, 2020). Large GTA grocery retailers , such as Loblaw Companies Ltd. (2019), Metro (2016) and Sobey's (2020), endorse procurement strategies which favour domestic produce.

Clarke and Tilman (2017) analyzed five paired greenhouse–open-field systems and demonstrated that greenhouse production tends to emit almost three times more GHGs than field systems due to the energy required to maintain the ideal growing conditions in the greenhouse. Wollenberg (2016) completed a study comparing global warming potential of various food groups and noted that 'the lowest median global warming potential values were for field grown vegetables (0.37 kg CO_2-eq/kg), slightly higher than fruit and vegetables from heated greenhouses (2.13 kg CO_2-eq/kg)'. Greenhouse fruit and vegetables from heated greenhouses were notably higher than field grown equivalents. Passive greenhouses with no auxiliary heating had emissions comparable with the upper quartile of some field grown fruit and vegetables (1.10 kg CO_2-eq/kg) (Wollenberg, 2016).
Table 1 summarizes the LCAs of lettuce that are available in the literature. LCAs were included in this comparison if the results for the emissions were in kg or g CO_2 eq, and the calculations were for a functional unit of 1 kg of lettuce.
For open-field lettuce production, the emissions range from 0.00356 – 0.857 kg CO_2 eq-1. Agricultural machinery operation and refrigerated trucks for transportation were the most impactful stages of the LCAs. For greenhouse lettuce, the emissions range between 0.453 – 4.19 kg CO_2 eq per 1 kg of lettuce. The emissions are highly dependent on whether the greenhouse is heated, and the energy source to heat the structure. The 2 cases where the greenhouses were heated with fossil fuels had the highest emissions per 1 kg of lettuce, exceeding 4 kg of CO_2 eq-1. When producing lettuce using an unheated hoop house, the largest contributor to the emissions was from the energy embedded in the the greenhouse infrastructure.

Table 1: CO_2 eq Emissions of Producing 1 kg of Lettuce.

Authors and Year	Country	Greenhouse (GH), Open-Field (OF)	Greenhouse Energy Source	Retailer Location	Total Emissions (kg CO_2 eq)
Plawecki et al. (2013)	U.S (Michigan)	GH	Unheated	Local	0.198
Hospido et al. (2009)	UK	GH	Natural Gas	Local	1.05-4.19
Hospido et al. (2009)	UK	GH	Unheated	Local	0.24
Marton and Kagi (2010)	Switzerland	GH	Fuel	Local	4.507
Marton and Kagi (2010)	Switzerland	GH	Waste Incineration	Local	0.453
Gunady et al. (2012)	Australia	OF	-	Local	0.00356
Plawecki et al. (2013)	U.S (California)	OF	-	Transported to Michigan	0.857
Hospido et al. (2009)	UK	OF	-	Local	0.25-0.41
Hospido et al. (2009)	Spain	OF	-	Transported to UK	0.36-0.54

RESEARCH GOALS

The research aims to answer the following: What is the carbon footprint from field lettuce imported from the U.S versus Canadian field and greenhouse lettuce and therefore what type of lettuce should Canadian be sourced by grocery retailers to reduce this footprint?

There are two primary objectives of the intended research:
To identify and acquire the data from greenhouses and fields in Canada, and from fields in the U.S., on the stages of production and transport of lettuce that result in the highest levels of carbon emissions; and
To recommend a source of lettuce with the lowest carbon emissions for retailers in the Greater Toronto Area (GTA).

RESULTS

DOMESTIC GREENHOUSES: To analyze the carbon emissions resulting from greenhouse structures, data from a case by Boulard et al. (2011) reported on Ecoinvent was analyzed. The study measures the amount of building materials used to build conventional plastic greenhouses in France, such as polyethylene, polystyrene, and steel for a lifespan of minimum 25 years, outlined in Table 2. A study by Pelletier & Godbout, (2017) confirmed that 90% of greenhouses in Quebec are typically made of polyethylene. The total, 0.175 kg CO_2 eq per m^2, was then amortized for the 25-year lifespan and converted to the functional unit. According to statistics provided by MAPAQ (L.-A. Gagné, personal communication, February 4, 2020), 30.65 kg of lettuce were produced per m^2 in 2015. It was concluded that the greenhouse structure is accountable for 0.006 kg of CO_2 eq^{-1}, see Diagram 1. The data from a study by Pelletier & Godbout (2017) was used to assess the CO_2 eq emissions from greenhouses in Quebec, which states that greenhouse horticulture and vegetable production in 2015 used the following energy sources outlined in Table 2. The energy is used for lighting, heating and irrigation, with various methods with varying degrees of efficiency. This overview is a yearly average as the amount of energy used varies each month.

DOMESTIC OPEN-FIELD: Open-field lettuce production in Canada is concentrated in Quebec, as 86% of lettuce was produced in Quebec in 2019 (Statistics Canada, 2020). To measure GHG emissions associated with the production practices of lettuce cultivation in Quebec, data on the type of machinery and fuel-use for land preparation, irrigation, fertilizer application and harvest were required but not available. For the purposes of this study, the emissions from the open-field lettuce production in California were used as a proxy. The differences in production practices are outlined in Table 3. Reviewing the production practices in Quebec in comparison to California demonstrates that there are many variables which much be considered in order to determine if one would result in more emissions than the other. At this stage, there is not data information available to confirm which source has higher emissions.

IMPORTED OPEN-FIELD: Canada imports lettuce from producers located in the U.S where majority of lettuce production is in California (CFDA, 2018). A case study by Plawecki et al. (2013) calculated the emissions associated with the use of agricultural machinery, outlined in Table 3, estimating that lettuce production in California results in a total of 0.171 kg CO_2 eq^{-1} .

TRANSPORTATION: There are 2 major distribution centers located in Ajax and Cambridge, Ontario for a large Canadian food retailer (D. Branson, Personal Communication, February 28, 2020). The estimated route between California producers to GTA distribution centers is 4035 km which would result in 0.207 kg CO_2 emissions. For greenhouse lettuce grown, specifically from Hydroserre Mirabel the biggest greenhouse producer in the province, the distance travelled is 583 km and results in 0.030 CO_2 emissions-1 kg^{-1} lettuce. Quebec open-field lettuce sourced primarily from Jardin de Napierville travels an average of 573 km, resulting in 0.029 CO_2 kg eq-1 kg^{-1} lettuce.

The data collected for this study are summarized in Diagram 1. The preliminary results demonstrate the CO_2 emissions associated with lettuce production in Canadian greenhouses are significantly higher than the other two sources. In greenhouse production, the stage resulting the highest levels of CO_2 emissions is Energy use, accounting for 95%. A mixture of fossil fuel energy sources consisting of light fuel oil (54%), along with natural gas (9%), propane (7%) and used oil (5%) are accountable for higher CO_2 emission levels then renewable alternatives. The energy mix consisted of 22% biomass energy which had minimal CO_2 emissions by comparison, only 0.004 kg of the total 0.758 kg of CO_2 eq. Imported lettuce resulted in a total of 0.378 kg CO_2 eq^{-1}. For the Canadian open-field lettuce, the emissions for this source are 0.2 kg CO_2 eq^{-1}. The stage of Fuel Use for Agricultural Machinery is accountable for 85% of the CO_2 eq emissions in this scenario. The transportation stages for the Canadian field-lettuce was less significant, resulting in around 0.30 kg of CO_2 eq, equivalent to 15%. In this study, domestic field-lettuce has the lowest CO_2 emissions eq^{-1}.

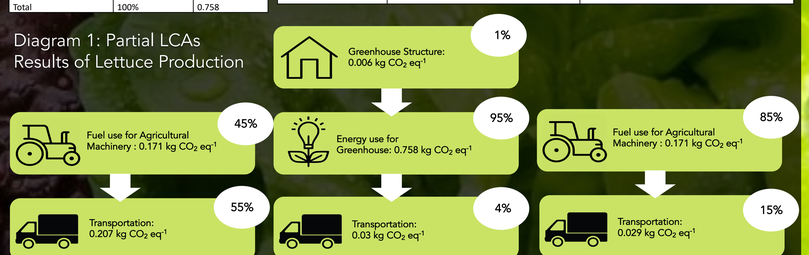
Table 2: Energy Sources in Quebec Greenhouses

	% of energy source used	Kg CO_2 eq1 kg^{-1} of lettuce
Light fuel oil	54.28%	0.511
Biomass	22.41%	0.004
Natural Gas	8.74%	0.070
Propane	6.74%	0.075
Used oil	4.74%	0.099
Electricity	2.47%	0
Geothermal	0.62%	0
Total	100%	0.758

Table 3. Open-Field Lettuce Production Practices

	California	Quebec
Land use 1 kg^{-1} lettuce	0.26 m^2	0.43 m^2
Types of soil	Silt loams and sandy soils in the southern deserts. Heavy clay soils in the Central Coast and Central Valley	Black organic soils
Amount of phosphorus fertilizer per hectare	280.2 kg	0 to 110 kg for sowed lettuce 30 kg for transplanted lettuce
Amount of nitrogen fertilizer per hectare	250.1 kg	60 to 150 kg
Plant to harvest time	65 to 80 days for midsummer plantings 130 days for late-fall and winter plantings.	70 days in the spring. 53 days in the summer to reach maturity. When transplanted, the growth cycle is 40-55 days.
Weeding	Manually	Commonly with a rototiller, occasionally manually or with chemicals
Space between plants	Row spacing is on beds is 102 or 203 cm wide. The 40-inch beds have 2 seed lines, and 80-inch beds can have 5 to 6 seed lines.	1-2 rows per bed, spacing is 25 or 53 cm wide. Between beds there are 45 cm where you can find 2 rows of lettuce.

Diagram 1: Partial LCAs Results of Lettuce Production



METHODOLOGY

A partial LCA analysis was completed for 3 sources of lettuce: greenhouse and open-field production in Canada and open-field production in the U.S. A functional unit of 1 kilogram of lettuce was used to calculate the CO2 emissions from all 3 sources of lettuce. The impact assessment focuses solely on CO_2 footprint rather than all overall environmental impacts.
The stages selected for this study were selected because of their significance in the literature outlined in Table 1.

Fuel use of Agricultural Machinery: To analyze fuel use for agricultural machinery, government data were collected covering all lettuce production in both the U.S. and Canada. Ideally, these data on fuel use for irrigation, land preparation and fertilizer application to assess all lettuce production and determine average GHG emissions from agricultural machinery in both respective countries. The reality is that practices can vary greatly on each farm and national data was not available. A case study extracted from a previous academic research on open-field lettuce production in California, by Plawecki et al. (2013). For domestic field lettuce, Quebec was identified as the province producing the largest amount of lettuce and supplying lettuce to locations in the GTA during the summer season. Government reports were available to determine the annual yield and land use practices of farmers in Quebec, but fuel use data were not. No case studies were previously completed, therefore grey literature was reviewed to further understand the farming practices in Quebec to compare to its international competitor.

Materials for Greenhouse Structures:. A life cycle assessment from EcoInvent, from a study by Boulard et al. (2011) provided the data necessary to assess carbon emissions associated with glass greenhouse structures which are commonly used in Quebec.

Energy use in Greenhouses: Government officials confirmed that Quebec is the largest producer of greenhouse lettuce in Canada. The data used in the study was report written by Pelletier & Godbout (2017), which provides an overview of energy use and sources in all Quebec greenhouses. The energy sources were converted using the emissions factors from Environment Canada (2019).

Transportation: It was assumed that all lettuce was packaged 24 heads per box. Plawecki et al. (2013) states that a 32-ton truck is assumed to carry a load of 31,751.5 kg of lettuce. The emissions were calculated based on a simplified route taken by trucks, between the farms to the retail distribution centers identified by Loblaw Companies Ltd. for their GTA locations. According to Environment Canada and Climate Change, the Vehicle CO_2 Emission Standards for a Class 8 sleeper cab truck from 2014-2016 with a high roof is 75 grams of CO_2/ton-mile (Environment and Climate Change Canada, 2013).

DISCUSSION

Recommendations for Retailers:

- Retailers should prioritize open-field lettuce in their procurement strategy. Canadian open-field lettuce emissions is estimated to have the lowest emissions, 0.2 kg CO_2 eq^{-1}. This source of lettuce is only available in the summer and should be prioritized during that season.
- To source lettuce during winter, imported lettuce resulted in lower emissions than greenhouse lettuce produced domestically. This result is consistent with the previous studies where the emissions associated with greenhouse vegetable produced with fossil fuel energy sources exceeded open-field emissions (Clarke and Tilman, 2017; Wollenberg, 2016; Hospido, 2009).
- To implement local purchasing strategies using Canadian greenhouses, it recommended that retailers consider the energy source used in the greenhouses as some may favour renewable energy and therefore would result in a lower carbon footprint.

Reducing Emissions:

- The type of energy used in greenhouse highly influences the CO_2 emissions from this source of lettuce. In the energy mix in Quebec greenhouses, the largest sources of energy are fuel oil (54.28%) and biomass (22.41%). If fuel oil were solely used in greenhouses, the emissions would increase from 0.758 kgCO_2 eq^{-1} to 0.941 kg CO_2 eq^{-1}. By comparison, if biomass was the only energy source, the total emissions from energy use in greenhouses would be 0.018 CO_2 eq^{-1}.
- In the case of imported lettuce, the carbon footprint from transportation is almost 6 times higher than domestic transportation emissions. The results of this study align with previous research where open field lettuce was transported long distances to consumers, where the refrigerated transport was responsible for the most significant GHG emissions in the LCAs and had higher emissions than local open-field lettuce.

Future Research:

- Primary data should be collected from producers to address significant gaps in the reporting of GHG emissions from production practices, in domestic greenhouses and open field farms. The lack of consistent and reliable data inventories is the main obstacle to using the LCA results in food-related policy making (Emhart et al., 2014). Reports highlighting the cost, hours and inputs such as pesticides and fertilizer required for production but failed to account for fuel use. This stage of the life cycle has proved to be significant in the carbon footprint of lettuce and therefore should be prioritized when collecting data in the future.
- The scope of this assessment did not include the CO_2 emissions associated with transporting greenhouse structures from the Netherlands. Further research is required to understand the supply chain of the greenhouse structures in Canada. If the materials are transported from the Netherlands, this stage of the life cycle may result in significant CO_2 emissions.
- A recommendation for future agricultural LCAs for Canadian greenhouse produce is to account for the seasonality of energy use in greenhouses. Separating data between winter and summer production accounting for varying production inputs could expose inefficiencies in the production methods which increase carbon emissions. Outlining the differences in CO_2 emissions for each month can influence the procurement strategy of retailers where sources can be favored on a seasonal or monthly basis. As a large retailer, Loblaw Companies Ltd. already has a seasonal procurement strategy and this assessment can re-enforce their decision.
- This study does not account for the reduced fuel efficiency in refrigerated trucks. Studies show that the CO_2 emissions due to the energy consumption by various processes such as energy consumption to power the refrigerator, were larger than that due to greenhouse gas leakage (Wu et al., 2013).

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