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MATERIAL FLOW IN THE ONTARIO DAIRY SUPPLY CHAIN

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ABSTRACT

We present a qualitative and quantitative analysis of material flow in the dairy supply chain in Ontario and describe the supply management system that governs the transactions within the supply chain. This study can be used as a basis for future studies to identify opportunities within supply management flows, improve the dairy supply chain in Ontario, identify potential vulnerabilities in the supply chain, to serve as a benchmark for studies of other supply chains.

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1 INTRODUCTION

Dairy supply chains produce raw milk which is then processed through a network of processors to produce finished products such as fluid milk, cheese, and yogurt. This paper provides a description of the physical processes and quantifies the material flow in the dairy supply chain in Ontario.

Material flow analysis is a resource accounting tool that provides a systems-based perspective, drawing links between the importation, consumption, and disposal of materials. The practice of MFA has been applied to different materials across various geographies. Characterizing the processes and quantifying the flow of material through the dairy supply chain is a critical first step in any process improvement endeavour. Thus, this study can be used as a basis for future studies to identify opportunities to improve the dairy supply chain, identify potential vulnerabilities in the supply chain, and to serve as a benchmark for studies of other supply chains.

2 LITERATURE REVIEW

This paper draws on and contributes to the literature that characterizes supply chains using material flow analysis (MFA) (Brunner and Rechberger, 2004). MFA studies have been used to identify opportunities for improving material resource efficiency. For example, (Ackom et al., 2010) used MFA to track the efficiency of wood utilization in sawmills. The paper identified the amount of sawmill residue available to the ethanol industry and quantified the gains economically, socially, and environmentally. Kuczenski and Geyer (2010) modeled the network of flows of polyethylene terephthalate (PET) in the U.S. The study identified interactions between primary and secondary PET in manufacturing, the potential to reduce virgin material, and overall insights into increased polymer cycling. Millette et al. (2019) conducted an MFA of plastics in Trinidad and Tobago using trade and waste characterization data. The results revealed opportunities for circular economy initiatives including banning polystyrene, recycling, and using low density polyethylene (LDPE) plastics as fuel in cement production. Elgie et al. (2021) extended the Millette et al. (2019) study on plastics to similar waste streams in tires and motor oil for Grenada, utilizing similar methodologies of combining disaggregated trade statistics with waste data for MFA. Van Eygen et al. (2017) analyzed plastic flows in Austria and determined required waste processing capabilities.

We contribute to the MFA literature by providing a material flow analysis of the dairy supply chain in Ontario. Dairy supply chains exhibit co-production, as raw milk is separated into distinct components that are recombined to produce various dairy products. This adds additional complexity to the mass balance calculations. The documentation of the processes and material flow in the dairy supply chain provides a foundation for future operational and policy studies.

3 DATA AND METHODOLOGY

We combine production data of producers and processors, import/export data, and consumption data to determine the flow of material through the dairy supply chain.

3.1 Producer and Processor Data

Producer (farmer) data includes dairy statistics on the number of farms and the total production of raw milk. This data was primarily obtained from the Dairy Farmers of Ontario (DFO), the Government of Canada, the Canadian Dairy Information Centre, and the University of Guelph.

Processor data includes data on dairy production statistics, provincially and federally licensed dairy processors, and product information (e.g., milk fat to litre conversions for raw milk, milk fat percentages, etc.). This data was obtained from the Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA), the Government of Canada, the Canadian Dairy Information Centre, University of Guelph, and interviews with industry experts.

3.2 Import/Export Data

Disaggregated trade (import/export) data for dairy in Canada was obtained for the year 2018 from the Canadian Dairy Information Centre from the Government of Canada. (Statistics Canada, nda) This information included data on imported and exported products (e.g., the harmonized system (HS) code, mass in kilograms, and value in Canadian dollars). The HS codes (product trade codes) were also mapped to product descriptions and used to categorize material by product type.

3.3 Consumption Data

The consumption data for fluid milk was derived from the commercial sales of milk and cream from Statistics Canada for the year 2018. This data was given in kilolitres sold per month, further separated into Standard Milk (also known as whole milk at 3.25% milk fat, 2% milk fat milk, skim milk, buttermilk, chocolate and other flavoured milk, and 1% milk fat milk. (Statistics Canada, ndb)

Consumption data for skim milk powder, condensed skim, butter, cheddar cheese, specialty cheese, dry whey, and yogurt was determined from per-capita consumption figures for each product type and population figures from 2018, all of which was taken from Statistics Canada for Ontario.

3.4 Methodology

The overall process for producing dairy products was determined through interviews with experts in industry and academia. Details on process steps were also obtained from the University of Guelph (Goff, nda) and the DFO (DFO, 2012).

To determine the flow quantities, we used a combination of primary data and mass balance calculations. Production quantities for raw milk and end-products were taken from the Canadian Dairy Information Centre. Production quantities of skim milk and whole cream were calculated using established raw milk composition data. Similarly, established composition data was used to determine the amount of milk fat required to produce all finished products, i.e., cream, butter, fluid milk, cheese, and yogurt. (Goff, ndb,n,n).

4 DAIRY PROCESSING AND MATERIAL FLOW

Dairy processing exhibits co-production or joint production characteristics. The first step is the production of raw milk (on dairy farms). Raw milk contains components that are separated and recombined in varying proportions to produce finished dairy products. Therefore, we can think of the production of raw milk as a the co-production of milk fat, solid-not-fats (SNF) (i.e., protein, carbohydrates, and minerals), and water – in specific proportions (International Dairy Foods Association, nd).

Typically, dairy processing begins with the separation of raw milk into skim and cream (see Figure 1). A centrifugal machine is used to separate the raw milk into skim milk and whole cream. Clarification of the raw milk can be done at the same time in the centrifuge to remove dirt, bacterial sediment, and other solids (Goff,

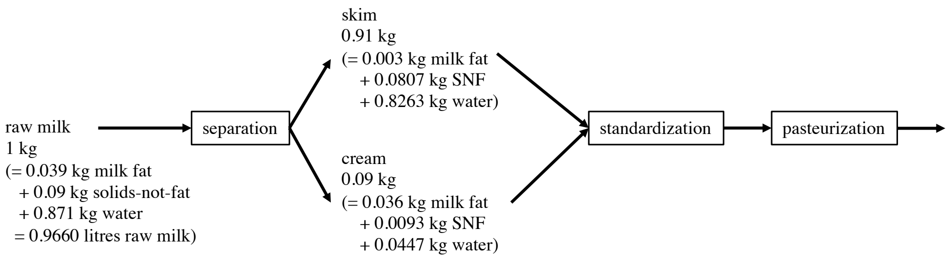


Figure 1: Basic milk processing steps: separation, standardization, and pasteurization. Assumptions: density of raw milk = ρ_{raw} = 1.0352 kg/L (Hill, 2021), skim consists of 90.8% water (International Dairy Foods Association, nd).

ndc). After separation, the skim and cream components are recombined to create a mixture with the appropriate fat content in a processed called standardization (AgriQuora, 2021).

After standardization, the milk and cream are pasteurized to ensure the destruction of all pathogenic microorganisms. The minimum temperatures and time requirements for milk pasteurization are set by regulation to ensure that milk and milk products are safe for human consumption (Goff, ndc). The most common method of pasteurization in Ontario consists of raising milk temperature very rapidly to at least 72 degrees Celsius for not less than 16 seconds, followed by rapid cooling (OMAFRA, nd). The standardized and pasteurized output is further processed with additional ingredients to produce finished dairy products.

Raw milk is used for for fluid purposes or industrial purposes (see Figure 2). For fluid purposes, milk used for table milk and cream (excluding sour cream). For industrial purposes, milk is used for manufactured products such as butter, cheese, yogurt and ice cream (Statistics Canada, 2021).

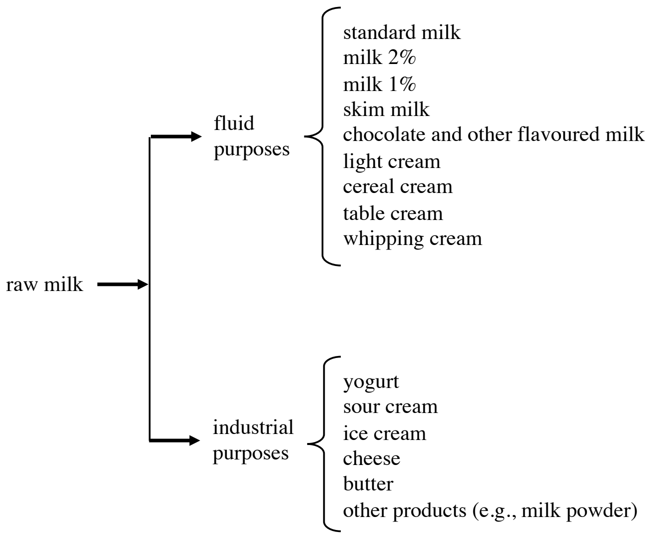


Figure 2: Dairy product categories (Statistics Canada, nde).

4.1 Fluid Purposes of Raw Milk

- **Fluid/Beverage Milk.** Fluid milk is sold with varying milk fat percentages: 0% (skim), 1%, 2%, and 3.25% (whole). The fat content is adjusted by either partially skimming the whole milk or completely skimming the milk and adding back the correct amount of cream to achieve the correct final fat content. Additional vitamins may also be added to the fluid milk (Goff, nde).

- **Cream.** Skim and cream streams are combined to make cream products: light cream (5-9.9% milk fat), cereal cream (10-15.9% milk fat), table cream (16-31.9% milk fat), and whipping cream (32% milk fat).

4.2 Industrial Purposes of Raw Milk

- **Yogurt.** To make yogurt, raw milk is first clarified, separated, standardized, and pasteurized. The milk mix is then homogenized. Yogurt starter is then added to the mix in a fermentation tank. Once the desired acidity is achieved, the fermentation tank jacket is replaced with cool water and agitation begins to stop the fermentation. The coagulated product is cooled; from here, fruits and flavours may be incorporated (Goff, ndb).

- **Ice cream and frozen desserts.** To make ice cream, first liquid and dry ingredients are combined into an ice cream mix. The mix is pasteurized and homogenized. The mix undergoes a freezing process which also incorporates air into the mix (Goff, ndf).

- **Cheese.** To produce cheese, milk is first standardized and pasteurized. Then the milk is inoculated with starter and non-starter bacteria to ripen. Rennet is then added to form the curd; the curd is allowed to ferment, then it is later cut. The whey is separated through heating, then later drained away. The curd forms a mat after the whey is drained away and these mats are cut and textured to expel any remaining whey, then the cheese pieces are either dry salted or brined. Finally, the salted curd pieces are placed in cheese hoops and pressed into blocks to form cheese (Goff, ndb). The temperatures, times, use of salting or brining, and aging varies based on the type of cheese being produced.

  The most common type of cheese is Cheddar. Other cheese are categorized as specialty cheeses that include Mozzarella, cream cheese, Parmesan, Swiss, Ricotta, Monterey jack, Colby, Feta, Gouda, Havarti, Provolone, among others.

- **Butter.** Butter is produced by churning whole cream and other non-dairy products. In some cases, the whole cream is ripened for the production of cultured butter by adding mixed cultures. Otherwise, the whole cream is placed in an aging tank where it goes through controlled cooling for 12-15 hours, so the milk fat achieves the correct crystalline structure for butter. The whole cream is then taken to be churned where it is agitated so the milk fat coagulates to create butter grains and buttermilk. The buttermilk is drained away from the butter grains. The butter can be salted and worked to improve flavour (Goff, ndb).

- **Other products.** Other products include powders (e.g., whole milk powder, skim milk powder, yogurt powder, sour cream powder, edible casein powders) and concentrated milk.

4.3 Material flow

Because of the co-production nature of dairy processing, we will consider a "base-unit" for material flow analysis. Of the three components of raw milk, milk fat is considered the most valuable and its production and use is tracked by the Dairy Farmers of Ontario, therefore, we will use milk fat as our base unit. The year 2018 will be used as a representative (pre-COVID) year for the material flow analysis.

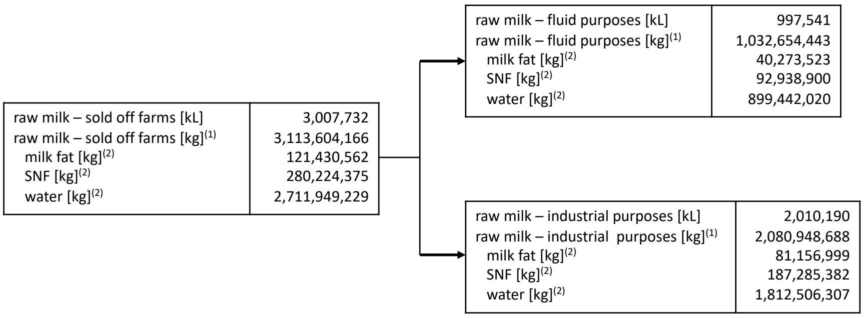


Figure 3: Raw milk production, fluid purposes, and industrial purposes in Ontario, 2018 (Statistics Canada, nde). Assumptions used for derived data: (1) density of raw milk = ρ_{raw} = 1.0352 kg/L, (2) Proportions of milk fat, SNF, and water are as given in Figure 1.

FLUID PRODUCTS. Fluid products are fresh products that cannot be stored, therefore, the mass balance equation for milk fat in Ontario is:

$$\begin{aligned} &\text{quantity Ontario milk fat used in fluid products production} \\ &+\text{quantity (imported - exported)} \\ &+\text{quantity (from other provinces - distributed to other provinces)} \\ =\ &\text{quantity sold} + \text{quantity loss from production, distribution, or sales} \end{aligned} \tag{1}$$

Figure 3 shows the production volumes for fluid products in Ontario for 2018. Figure 4 shows the commercial sales of fluid products in Ontario. Detailed production data for specific fluid products was not available. Comparing the total milk fat used in fluid products production (40,273,523 kg) with the total milk fat in fluid product sales (50,272,150 kg) reveals that there must have been net influx of fluid products (either from imports or other provinces) into Ontario comprising of 9,998,627 kg of milk fat.

	TOTAL [kL]	density [kg/L]	TOTAL [kg]	kg milk fat per kg product	TOTAL milkfat [kg]
Standard milk	117,880	1.033	121,770,040	0.0325	3,957,526
Milk 2%	495,899	1.034	512,894,047	0.0200	10,257,881
Milk 1%	151,594	1.035	156,943,470	0.0100	1,569,435
Skim milk	58,914	1.036	61,034,904	0.0030	183,105
Chocolate and other flavoured milk	80,352	1.060	85,173,120	0.0140	1,188,165
Light cream	11,752	1.021	11,998,792	0.0745	893,910
Cereal cream	57,115	1.027	58,657,105	0.1295	7,596,095
Table cream	64,968	1.021	66,332,328	0.2395	15,886,593
Whipping cream	27,094	1.008	27,310,752	0.3200	8,739,441
				TOTAL	**50,272,150**

Figure 4: Fluid product sales in Ontario, 2018 (Statistics Canada, ndf). Sources for density and milk fat content: Goff (ndd); Nicholson (2020); Statistics Canada (2020); Hill (2021).

Import data shows that 21,559,672 kg of milk and 1,191,314 kg of cream was imported into Ontario in 2018 (Figure 5) (Statistics Canada, nda). The breakdown of the types of milk and cream imported was not given. However, even if we assume that the imported milk and cream had the highest milk fat content possible (i.e., 4% milk and 32% cream), the total amount of milk fat in the imported products would

		[kg]
Milk		21,559,672
Cream		1,191,314
Cheese	Cheddar and cheddar types	2,237,756
	Specialty Cheese	11,191,210
	Processed Cheese	611,509
	Fresh Cheese	229,267
	Total Cheese	**14,269,742**
Ice Cream and Ice Cream Novelties		993,103
Yogurt		161,958
Butter and other fats and oils derived from milk		16,668,083
Evaporated Milk		878,785
Condensed Milk		405
Skim Milk Powder		3,585,729
Whole Milk Powder		1,662,137
Whey Products		14,562,047
Casein and Casein Products		1,262,331
Dairy Spreads		23
Products Consisting of Natural Milk Constituents		2,855,965
Milk Protein Substances		6,987,321
Others		11,630,825
TOTAL DAIRY PRODUCTS		**98,269,440**

Figure 5: Dairy products imported into Ontario, 2018 (Statistics Canada, nda).

only account for 1,243,607 kg. This leaves $9,998,627 - 1,243,607 = 8,755,020$ kg of milk fat unaccounted for. Using Equation (1) gives us,

$$\begin{aligned}
&\text{quantity (from other provinces - distributed to other provinces)} \\
&\quad - \text{quantity exported} - \text{quantity loss} \\
&= \text{quantity sold} - \text{quantity ON milk fat used in fluid products} - \text{quantity imported} \\
&\geqslant 50,272,150 - 40,273,523 - 1,243,607 \\
&= 8,755,020 \text{ kg} \qquad (2)
\end{aligned}$$

The positive number given in Equation (2) implies that Ontario is receiving milk from other provinces. Our data does not reveal whether the milk is in the form of raw milk or finished product. If the milk is in raw milk form, then the raw milk would be going to processors. This would imply that Ontario's processing capacity of fluid products exceeds its milk production capacity that is allocated to fluid products. However, if the milk is in finished product form, it would flow directly into distribution channels, which would indicate that the capacities for producing and processing raw milk for fluid products are balanced. There could also be a mixture of raw milk and finished fluid products coming into Ontario. More data into the production quantities of fluid products (versus that sales quantities that are currently used for this analysis) would shed further light on this issue.

INDUSTRIAL PRODUCTS. The mass balance equation for industrial products is similar to that for fluid products. Although we do not have consumption data for industrial products, we have (incomplete) production data at the product class level. Therefore, the mass balance equation will equate production quantities. The mass balance equation for milk fat use in the production of industrial products in Ontario is:

$$\begin{aligned}
&\text{quantity Ontario milk fat used in production of industrial products} \\
&\quad + \text{quantity (imported - exported)} \\
&\quad + \text{quantity (from other provinces - distributed to other provinces)} \\
&= \text{quantity used in production of industrial products} \\
&\quad + \text{quantity loss from production} \qquad (3)
\end{aligned}$$

Figure 6 shows the production quantities of industrial products. Although the production data is incomplete, the total milk fat of the available data in the last column of Figure 6 sums to 93,269,263 kg. Thus, the total amount of milk fat used in industrial products produced in Ontario is greater than or equal to 93,269,263 kg. This amount is greater than the amount of Ontario milk fat used for industrial purposes shown in Figure 3 (81,156,999 kg). Using Equation (3) gives us,

$$\begin{aligned}
&\text{quantity (imported - exported)}\\
&+\text{quantity (from other provinces - distributed to other provinces)}\\
&-\text{quantity loss from production}\\
=\ &\text{quantity used in production of industrial products}\\
&-\text{quantity ON milk fat used in production of industrial products}\\
\geqslant\ &93,269,263-81,156,999\\
=\ &12,112,264\text{ kg} \qquad (4)
\end{aligned}$$

The positive number given in Equation (4) implies that Ontario must be importing milk or milk products for the purpose of producing industrial products. Import data shows that industrial dairy products were imported into Ontario (Figure 5). This analysis suggests that Ontario's processing capacity for industrial products is greater than the milk production capacity that is allocated to industrial products.

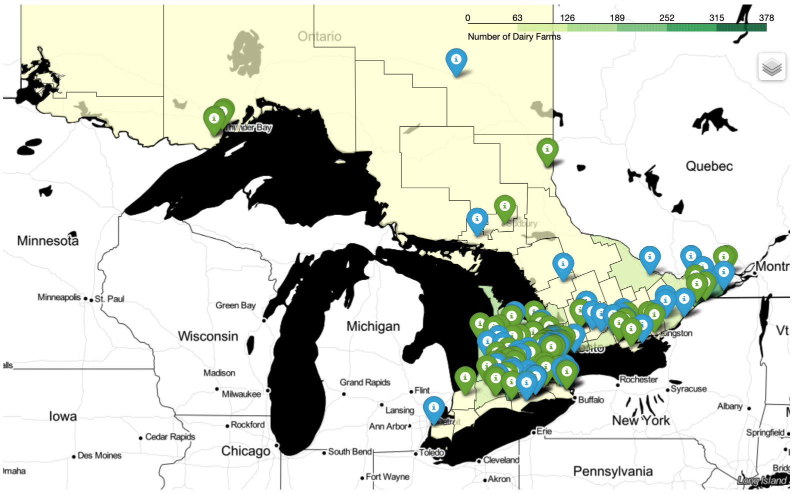
	TOTAL	density [kg/L]	TOTAL [kg]	kg milk fat per kg product	TOTAL milk fat [kg]
	tonnes				
Cheddar cheese (1)	63,319	N/A	63,319,000	0.311	19,692,209
Speciality cheese (2)	94,854	N/A	94,854,000	0.273	25,890,491
Yogurt (3)	70,385	N/A	70,385,000	0.016	1,147,276
Butter (4)	32,988	N/A	32,988,424	0.800	26,390,739
Concentrated whole milk (5)	..				
Sweetened concentrated milk (5)	..				
Skim milk powder (5)	..				
Partly skimmed concentrated milk (5)	..				
	kL				
Hard ice cream (6)	105,782	0.849	89,777,183	0.13	11,671,034
Soft ice cream (6),(7)	x	0.549		0.1	
Ice cream mix (6)	59,106	1.103	65,211,650	0.13	8,477,514
Milkshake mix (8)	..				
Sherbert (8)	..				
Water ices (8)	..				
Ice milk mix (8)	..				
Hard frozen yogurt mix (8)	..				
Soft frozen yogurt mix (8)	..				

Figure 6: Industrial products production volumes in Ontario, 2018 (Statistics Canada, ndd,n). (1) Source: Milk fat content (Nicholson, 2020). (2) Assumption: Most of the volume of specialty cheeses is Mozzarella with some other higher fat content cheeses, therefore, assume fat content is slightly higher than Mozzarella cheese. (3) Milk fat content - see Appendix B. (4) Butter production volume for Ontario in 2018 is not available. Therefore, this number was approximated by averaging the percentage of Ontario production in Canada for years 2014, 2015, 2015, 2019, and 2020 (28.4%). (5) Ontario production volume was not available, only aggregate Canada production. (6) Milk fat content - see Appendix A. (7) Data suppressed to meet the confidentiality requirements of the Statistics Act. (8) Data not available for the specific reference period.

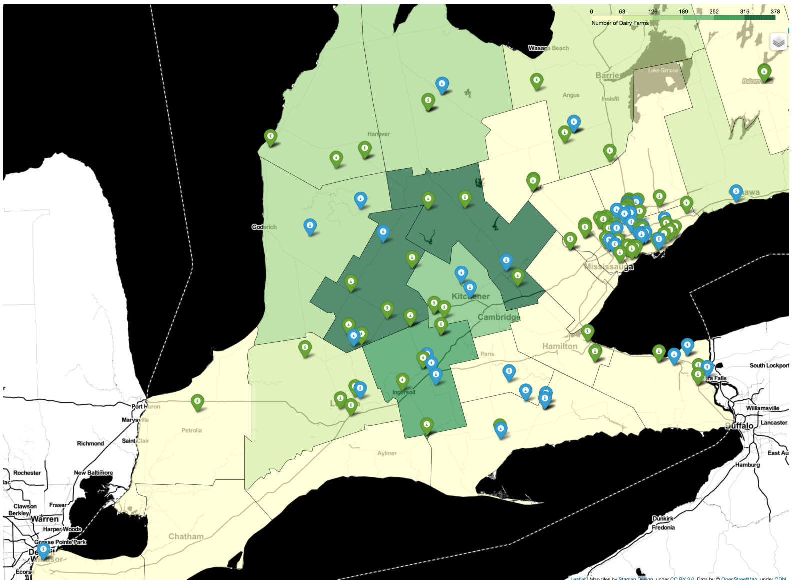
5 DAIRY SUPPLY CHAIN IN ONTARIO

5.1 Producers

In 2018, there were 3446 dairy producers (farms) in Ontario (Canadian Dairy Information Centre, 2020a). The DFO organizes dairy producers into 12 different regions based on dairy producer committees (DFO, 2016).



(a) All of Ontario.



(b) Southwestern Ontario.

Figure 7: Dairy producers and processors in Ontario (OMAFRA, 2016, 2020). Shading indicates the density of producers in the county. Blue markers indicate federally licensed processors, green markers indicate provincially licensed processors.

5.2 Processors

There are 60 provincially licensed and 104 federally licensed dairy processors (Canadian Dairy Information Centre, 2020b) (Figure 7). Provincially licensed processors can only sell products within Ontario whereas processors that are federally licensed can also distribute finished products outside of the province or internationally. Processors sell their goods through distributors or directly to retailers or food service organizations, who then sell to consumers. Figure 7 shows the location of dairy producers and processors in Ontario.

5.3 Channels of Distribution/Dairy Distribution

Dairy products in Ontario are distributed through two primary channels: dairy wholesalers and supermarkets and grocery stores in Canada (Couillard, 2020). Many dairy producers in Canada are members of cooperatives that are technically not defined as dairy wholesalers, but rather as vertically integrated dairy producers.

Increasingly, vertically integrated dairy producers carry out their own wholesaling and distribution activities (Koronios, 2021). Wholesaler revenue comes from five major markets:

1. Food service outlets including restaurants, hotels, motels, industrial catering, airlines, and accommodation venues. This comprises 11% of the dairy wholesaling industry in Canada.
2. Retailers including supermarkets, mass merchandisers, super centres, and convenience stores, representing 38.2% of revenue in Canada.
3. Other wholesalers. This includes revenue from manufacturer sales branches and offices who sell to traditional wholesalers, national wholesalers selling to regional wholesalers, and wholesale from dairy specific wholesalers to general wholesalers. This accounts for 29% of industry revenue in Canada.
4. Food manufacturers and processors purchase dairy ingredients to manufacture other food products. This comprises 16.8% of revenue in Canada.
5. Other represents 5% of the remainder of industry revenue.

Most distributors are small private regional enterprises which serve local markets. The distribution of fluid milk is highly regulated in Ontario to maintain product safety and quality pursuant to the Milk Act. Distributors are classified as either a "shopkeeper-distributor" or "non-shopkeeper-distributor".

Shopkeeper-distributors buy fluid milk products from non-shopkeeper-distributors and sell or distribute more than 50% of this volume directly to consumers. They are typically retailers such as grocery stores, specialty food stores, convenience stores, and warehouse clubs, as well as service restaurants, caterers, and coffee shops. They are inspected by local public health units under the *Health Protection and Promotion Act* (Ontario) and Regulation 493/17 - Food Premises.

Non-shopkeeper distributors of fluid milk products do not distribute more than 50% of their volume directly to consumers and are typically wholesalers who sell the majority of their fluid milk products to other distributors such as retailers. As such, they must be licensed by the Food Safety Inspection Delivery Branch under the OMAFRA to ensure delivery vehicles and storage facilities comply with regulatory requirements. There are 178 non-shopkeeper distributors licensed in Ontario as of May 2020 (OMAFRA, 2021a,b).

5.4 Regulated, Centralized Supply Management of Milk Production and Processing

The dairy industry operates under a supply management system which limits the supply of products according to expected consumption in the Canadian market in order to ensure predictable, stable prices. The Canadian Milk Supply Management Committee (CMSMC), chaired by the Canadian Dairy Commission (CDC), is the key policy decision making body under the National Milk Marketing Plan. CMSMC determines the national domestic supply of milk and allocates volume across regions. However, control over the fluid milk market is controlled by provincial jurisdictions (OMAFRA, 2014). The system relies on three pillars: production control, pricing mechanisms, and import control. In Ontario, the supply management system is managed by the Dairy Farmers of Ontario (DFO) (DFO, 2018).

PRODUCTION CONTROLS. The DFO serves as the marketing agency which determines production quantities for both fluid and industrial milk production. Dairy producers are limited to the production quantity specified by their respective quotas. Producers' quotas are expressed in terms of kilograms of daily butterfat (OMAFRA, 2014). The farmers can bid to buy or offer to sell quotas via the Dairy Farmers of Ontario Quota Exchange (DFO, 2021; Canadian Dairy Information Centre, ndb).

According to the "Milk Act," the DFO is the only legal purchaser and seller of unpasteurized (raw) milk in Ontario (Government of Ontario, 1990). All raw milk from producers is sold to the DFO. Processors order milk from the DFO and the DFO invoices processors according to the use of the raw milk components. There are 5 different classes of milk products which define all milk utilization according to their final end-use (Canadian Dairy Commission, 2020). Fluid plants process dairy products under Class 1 which primarily includes fluid/beverage milk, creams, and flavoured milks. Processors of fluid products and Class 2 products (e.g., yogurts, milkshakes, frozen desserts) are supplied on-demand. Industrial plants that process Class 3 and 4 products (e.g., specialty products, butter, powder, evaporated milks, cheeses) are allotted a plant supply quota which entitles them to a share of the available raw milk supply after the on-demand requirements have been met. Class 5 products do not require allocations (DFO, 2021).

PRICING MECHANISMS. Processors pay for milk based on milk use class, i.e., Class 1, 2, 3, 4, or 5. Each product within a milk class is priced based on the kilograms of milk fat, protein, and other solids (Canadian Dairy Information Centre, nda). As milk is sold and delivered in advance of payment, the DFO requires assurances that processors have sufficient equity to cover approximately two months' worth of milk purchases (DFO, 2019). The price of milk is updated annually to reflect the cost of producing milk and inflation (Canadian Dairy Commission, 2021). The formula used for the price adjustment in percentages is fifty percent of the variation in the cost of production plus fifty percent of the consumer price index.

Not all the classes of milk in the harmonized milk classification process use the same method to update milk prices; prices of milk used in classes 5(a), 5(b), 5(c), 4(a) (solids other than fat) and 4(m) are set differently. For milk classes 5(a)-(c), the price of milk is set monthly, taking into account variations in the price of similar dairy products produced in the United States for classes 5(a) and 5(b), and rest of the world for 5(c). For Milk Class 4(a), the price of solids other than fat are set monthly using a methodical formula from the Canada–United-States–Mexico Agreement (Mussell, 2016). The updated prices are posted monthly and can be found on the provincial website (`milkingredients.ca`).

IMPORT CONTROL. The federal government of Canada limits dairy product imports through the use of tariffs. Canada sets tariff-rate quotas. Foreign goods totalling approximately 10% of Canada's domestic dairy market enter tariff-free, but all other imports face high tariffs to prevent foreign foods from flooding the Canadian market. In comparison, the United States gives foreign dairy products access to 2.75% of its domestic market.

6 CONCLUDING REMARKS AND EXTENSIONS

The dairy supply chain is a complex web of interconnected processes and organizations. The supply chain is further complicated by the co-production nature of the processes. Raw milk components are separated and used in varying proportions for different dairy products. In this report, we focused on the milk fat component. Even with this first order analysis and incomplete data, our analysis suggests that there is a net inflow of fluid dairy products into Ontario, and that Ontario's processing capacity for industrial dairy products is greater than the raw milk production capacity for fluid products. This has implications for supply chain resilience (e.g., the dependence on out of province supply chain partners, logistics), and employment in Ontario.

Two logical extension to this study would be a material flow analysis of adjacent provinces, and the incorporation of the flow of SNF in the supply chain. This report focused on the primary use of raw milk, but secondary uses of by-products is another fruitful extension of this analysis. Understanding the full interconnectedness of the organizations in the dairy supply chain can shed light on vulnerabilities and strengths of the supply chain to withstand supply side or demand side disruptions. Whereas production of raw milk is below the quantities needed for commercial uses in industrial products, we do not know the utilization level of the total production capacity as demand for locally produced industrial products is unknown. Understanding co-production interdependences in relation to local demand for these products can reveal interesting insights on the resilience of the province and its dairy system.

Additionally, this analysis relied on possibly inaccurate or incomplete data, or incorrect assumptions about milk fat content in various dairy products. A fruitful extension to this study should incorporate sensitivity analysis on assumptions and build in confidence intervals around data estimations.

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A ICE CREAM COMPOSITION AND DENSITY

The composition and density of various types of ice cream are given in Figure 8.

percentage	hard ice cream	low fat and light ice cream	soft-frozen ice cream	sherbert and sorbet	frozen yogurt	ice cream mix (1)
milk fat	13	5	10	1.5	2	13
SNF	10.5	12.5	12	3.5	14	10.5
sucrose	14	11	10	24	15	14
corn syrup solids	3	5.5	4	6	0	3
stabilizer	0.3	0.35	0.15	0.3	0.35	0.3
emulsifier	0.14	0.1	0.15	0.7	0	0.14
Total solids	**40.94**	**34.45**	**36.3**	**36**	**31.35**	**40.94**
water	59.06	65.55	63.7	64	68.65	59.06
density [kg/L of mix]	1.103	1.118	1.099	1.145	1.120	1.103
overrun	0.300	1.000	1.000	1.000	1.000	0.000
density [kg/L ice cream]	0.849	0.559	0.549	0.572	0.560	1.103

Figure 8: Ice cream composition and density. Source: (Goff, ndf). (1) The composition of ice cream mix is assumed to be the same as hard ice cream, but the overrun (amount of air) is assumed to be zero.

B YOGURT FAT CONTENT

The fat content of yogurt was approximated according to the weighted average shown in Figure 9.

yogurt type	percent fat	percent sales (1)
low fat	2.0	49.0
fat free	0.4	35.2
whole	3.3	15.1
reduced fat	1.0	0.7
weighted average	**1.63**	

Figure 9: Weighted average fat content of yogurt according to sales in the U.S. in 2018. Source: (Statista, 2018). (1) The percentage sales by fat content in Ontario was assumed to be the same as in the U.S.