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Over 6 billion liters of Canadian milk wasted since 2012

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ABSTRACT

Canada's dairy supply management system provides milk year-round but unnecessarily disposes of overproduction. A lack of transparent data on discarded milk means that the scale of this issue is unknown. This hinders actions to mitigate the potentially large environmental, economic and nutritional costs of avoidable, on-farm milk waste. Here we estimate the volume of surplus milk discarded on farms using a material flow analysis approach, and assess the related environmental and nutritional costs. By our estimates, over 6.8 billion liters of raw milk vanished from Canadian dairy farms since 2012 (totaling a value of $14.9 billion CAD). We calculate this is equivalent to 8.4 million tonnes of CO_2 emissions and enough milk for 4.2 million people (11 % of the Canadian population) annually. We suggest increasing transparency on the volume overproduction, reducing incentives for farmers to overproduce, and updating quotas to reflect shifting dietary needs as actions to align the Canadian dairy sector with broader food-system sustainability objectives.

1. Introduction

Canada is unique amongst large dairy producing countries in that it still has a dairy supply management system (DSMS) (Kempen et al., 2011). The DSMS aims to match milk supply and demand by constraining the volume of milk on the market via production quotas set by provincial dairy boards (Peta, 2019). The intent of the DSMS is to support farmers and provide dependable domestic milk and butterfat supplies. However, supply always outstrips demand because cow lactation is variable and dairy farmers are incentivized to exceed their quota and discard excess milk rather than underproduce and lose revenue.

Discarded milk is not only a nutritional and economic loss, but also needlessly consumes dwindling resources while emitting greenhouse gases (GHGs) and polluting air, soil, and water (Arsenault et al., 2009). The Canadian diet is amongst the most environmentally intensive globally (Ivanova et al., 2016) and many Canadian households are increasingly reliant on food banks (Daly et al., 2023).

While this study focuses on Canada's DSMS and the resultant milk waste, similar challenges are observed globally, emphasizing the universal nature of agricultural waste and resource inefficiency in dairy production. Countries with large dairy industries, such as the United States, New Zealand, and members of the European Union, also grapple with the complexities of balancing milk production with market demand, albeit through varying regulatory frameworks (Boyer and Charlebois, 2007).

In the United States, for example, milk dumping occurs, though at lower rates due to different market dynamics and less restrictive quota systems. Comparatively, New Zealand, a leading exporter without milk quotas, manages surplus through market-driven mechanisms, which offer a contrasting approach to Canada's system. European Union countries have recently transitioned away from a quota system, facing new challenges related to overproduction and environmental impacts.

The Food Waste Hierarchy framework proposed by Papargyropoulou et al. (2014) describes prevention as the most favourable option. This emphasizes avoiding surplus food generation and avoidable waste in the supply chain. They go on to describe the important difference between waste management and waste prevention. In the particular case of milk production, this is the least environmentally harmful, but has the potential to produce unintended consequences as it may not always address the underlying drivers (O'Connor et al., 2023). O'Connor et al., 2023) go on to argue that data scarcity hinders the depth of understanding required to develop systemic solutions to agricultural on-farm waste.

Given the dual challenges of reducing the environmental impacts of

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agriculture and eliminating food insecurity, an understanding of the amount of milk discarded under the DSMS is urgently need.

The challenge of surplus milk production is rarely acknowledged by the industry and surpluses are treated as isolated incidents (Tamilia and Charlebois, 2007). There is little transparency and data on surplus milk discarded in Canada are sparse. The limited data that are available for the Province of Ontario suggest the volume is immense (Dairy Farmers of Ontario (DFO), 2022).

To overcome this gap, we quantified surplus milk between 2012 and 2021 using a mass-balance method. We estimated the milk production based on herd size and average milk yield per cow lactation, and subtracted the farm gate sales to infer the amount of milk that never left the farm. We combined these estimates with intensities of GHGs, land use, and water use per liter of milk to quantify the environmental costs of surplus milk (Wernet et al., 2016).

2. Methods

Milk sale are publicly available from the Statistics Canada (Statistics Canada, 2023a), although these figures do not include the dumped milk, nor the amount produced prior to dumping.

We estimated total milk production at dairy farms by multiplying the average annual milk yield per cow lactation (subtracting milk consumed by calves) (International Committee for Animal Recording (ICAR), 2022) by the total head of dairy cattle according to the national census of agriculture (Statistics Canada, 2023b). We assume dairy cattle are productive for 305 days a year (International Committee for Animal Recording (ICAR), 2022). Production statistics are breed-specific as are the estimates of head of cattle in each province (Statistics Canada, 2023b). We multiplied head of cattle for each breed in each province by the breed-specific milk yield per cow and summed to estimate total national raw milk production for the years 2012 to 2021. Then we estimated the volume of raw milk consumed by calves assuming one calf per lactation, weaning at eight weeks, no milk replacer used (although it is known that 50 % of Canadian dairy farms use a mixture of fresh milk and milk replacer, and 11 % use exclusively milk replacer) (Vasseur et al., 2010).

After estimating raw milk production, we subtracted the volume of milk sold by dairy farms to processors (Statistics Canada, 2023a) to infer the amount of milk produced at dairy farms that never left the farm gate. Unaccounted milk is assumed to be on-farm discarded milk. Using the above on-farm use estimate leads to a lowest case estimate of discarded milk (6.8 billion liters over the decade), and the true number likely sits higher. When on-farm use is not subtracted, this leads to a highest case discarded milk, at 9.7 billion liters over the decade.

This is only an estimate of discarded milk. Lactation rates vary between individual cattle and throughout the year. However, lactation statistics are based on representative sample sizes and should provide accurate estimates of raw milk production within acceptable error thresholds, especially when considering milk production across the entire Canadian dairy herd. Nonetheless, we included a standard deviation (error factor two) of the total value based on the fluctuations over the decade of annual estimates, and provide both upper and lower estimates in our calculations to account capture uncertainties in our estimate.

Life cycle inventory data from milk production in Quebec, Canada, including all upstream activities such as fertilizer and feed production and transportation, operation of farm machinery, was used to calculate the environmental burdens from cradle to the farm gate. Milk quantities in kilograms were multiplied by the global warming potential, water footprint, and land use impact factors, available from the ecoinvent v3.7 life cycle inventory database (Wernet et al., 2016). The impact factors were characterized using the ReCiPe midpoint (H)[1] method (Huijbregts et al., 2017). Quebec is the largest dairy producing province in Canada (36 % of farm sales by volume), and production practices there should be representative of other Canadian provinces (Statistics Canada, 2023a). The extended method, including all equations, variables, and data sources is provided in the **Supplementary Information**.

3. Results

Fig. 1 shows total milk and estimated discarded milk in Canada from 2012 to 2021. Canadian cows produced an estimated 96.2 billion liters of milk in this period, but dairy farmers only reported selling 86.4 billion liters. This suggests that 6.8 billion liters of milk or approximately 7 % of total production vanished on-farm. While some of this milk was likely discarded by farmers or rejected by processors for noncompliance with food safety rules or lack of producer capacity, this volume is likely negligible in Canada's advanced dairy industry (March et al., 2019; Charlebois et al., 2021).

The environmental costs of this wastage between 2012 and 2021 were immense (Table 1). The total carbon emissions from discarded milk were 620–1270 MT of carbon dioxide equivalents (range accounts for factor 2 uncertainty in discarded milk estimates). This is equivalent to the annual GHG emissions from 350,000 passenger vehicles in North

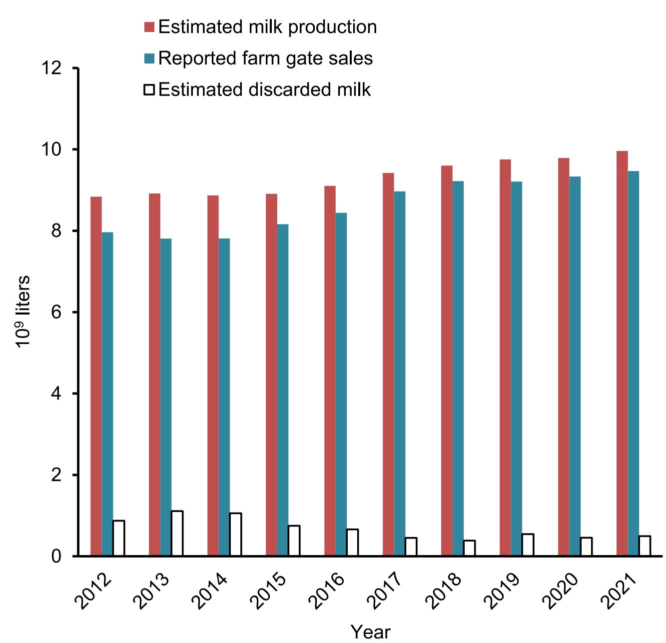

Fig. 1. Estimated discarded milk in Canada between 2012 and 2021.

[1] We selected midpoint (H) as it gives climate change impact in GWP100, as it used in the IPCC assessments. Midpoint (H) is also the moderate set of characterization factors between the other two options: ReCiPe (Egalitarian), which uses GWP20 (emphasizing the need for curbing GHGs immediately), and ReCiPe (Individualist), which uses GWP500 (de-emphasizing the risk of climate change). By choosing midpoint (H), we conform to the orthodox discourse on climate change, and in doing so our climate change impact results could be seen as a conservate estimate

Table 1
Estimated environmental, nutritional, and social costs of milk discarded under the Canadian Dairy Supply Management System between 2012 and 2021.

Indicator	Unit	Decadal Total	Mean	Std. Dev.	Max	Min
Environmental						
Climate	kilotonnes CO_2-equivalents	8676	868	316	1419	492
Land	square kilometers	13,021	1302	474	2129	739
Water	cubic kilometers	13,134	1313	478	2148	745
Nutritional						
Energy	kilocalories (10^9)	4191	602	160	868	423
Fat	kilotonnes	277	39.9	9.97	56.3	28.4
Protein	kilotonnes	228	32.8	8.37	46.8	23.1
Social						
Economic	Million Canadian $	14,858	1486	159	2187	921
Surplus Cattle	Head of cattle	710,151	71,015	28,257	119,586	38,972

America (Davis and Sallee, 2024; Lodi et al., 2018). Producing wasted milk required 920–1900 km^2 of arable land and 930 million to 1.9 billion m^3 of surface and groundwater, both for direct care of dairy cattle and indirectly for growing feed. The nutritional opportunity costs of discarding milk are also substantial (Table 1). By our estimates, the retail value of dumped milk volume over the last ten years is $14.9 billion CAD, averaging $1.5 billion CAD per year with a value of $1.3 billion CAD in 2021, the most recent available year.

In terms of lost nutrition, discarded milk represents 298–611 million lost kilo-calories, 20–39 Mt. of lost fat, and 16–33 Mt. of wasted protein. This equates to throwing out the recommended annual dairy intake for between 3.0 and 6.1 million Canadians (Elliot, 2022).

4. Discussion

It is difficult to attribute our calculated milk losses solely to the DSMS. Farmers discard milk for a variety of reasons, such as low market demand, limited processor capacity, presence of antibiotic residues, or damaged farm infrastructure (Wolf et al., 2021).

The challenge of attributing milk losses solely to Canada's DSMS is complex, influenced by several unique factors within the Canadian dairy sector (Agriculture and Agri-Food Canada, 2021). For example, the fluctuations in discarded milk as depicted in (see Fig. 1) could be due to several interrelated factors, including variations in milk production driven by changes in farming practices or cattle health, shifts in market demand affecting the amount of milk sold, and environmental conditions that influence dairy operations (O'Connor et al., 2023). Additionally, processing capacity constraints during certain years might lead to increased wastage if excess milk cannot be timely processed or stored. The decreasing levels of discarded milk over the years can likely be attributed to a combination of improved farm management practices, advancements in dairy processing technologies, stricter adherence to regulatory standards, and better supply chain coordination. Enhanced farming techniques have allowed for more precise control over milk production, closely matching it with market demand and reducing excess.

These challenges afflict Canadian farmers and those in countries without quota systems. Available data do not support post-hoc analysis of on-farm wastage rates before and after the quota was introduced in 1972. However, comparisons to peer countries with advanced dairy industries are telling. In the United States, where "milk dumping" is monitored, discard rates are typically 0.2 to 0.5 % (Wolf et al., 2021). Surveys of dairy farms revealed on-farm wastage rates of 0.3 % in Sweden, 0.5 % in Finland, 1.8 % in Scotland, and 3.5 % in France (March et al., 2019). This suggests that Canadian dairy farms discard milk at an elevated rate compared to their peers.

Assuming the DSMS is wasteful, the system still has its advantages. Supply management stabilizes supply and farm receipts. Eliminating the DSMS and increasing milk supply could bottom-out prices, forcing farmers to produce more and perversely increase wastage across the system (e.g., at the retailer or consumer). Given that the DSMS is unlikely to disappear anytime soon, we suggest the following reforms to enhance transparency of the DSMS disincentive overproduction.

1) The Canadian Dairy Commission Act should be updated to phase out the legal practice of discarding milk that meets food safety standards. However, to avoid farmers surreptitiously dumping milk, additional policies are needed.
2) Monitor and publish estimates on discarded milk. There is little transparency surrounding surplus milk. The Canadian Dairy Commission should pay farmers to document and report volumes of milk discarded, as is done in the United States (Wolf et al., 2021). Publishing surplus milk statistics based on head of productive cattle (as in our analysis) would provide motivation for the industry to reduce herd size and transition towards alternatives such as plant-based dairy.
3) Reducing flexibility in the DSMS to overproduce. Canadian dairy farmers are allowed to sell excess milk to willing buyers if they pay a penalty. Farmers can also buy quotas from underproducing farms. Conversely, farmers are penalized for underproducing (as milk has been committed to processors) and they lose revenue. Thus, the DSMS leans towards promoting surplus milk. To reverse this, the penalties for underproducing should be lower than those of overproducing. Farmers that are consistently buying quotas from other farmers should also be penalized. These changes might reduce the amount of milk available on the market, but the considerable wastage rates by retailers and consumers suggest that too much Canadian dairy is produced at present (Elliot and Levasseur, 2022).
4) Review the process by which quotas are set. The quota system is based on the antiquated notion that milk is a staple of a nutritious diet and that demand for milk cannot be substituted by plant-based alternatives. The nutritive necessity of milk has been disproved (Ludwig and Willett, 2013), while popularity of plant-based dairy alternatives is increasing (Elliot, 2022; Gardner and Hauser, 2017). *Re*-formulating quotas to meet a portion of dairy-like product demand, acknowledges the growing importance of plant-based alternatives to dairy milk, and helps prioritize the necessary shift towards environmentally friendly diets (Willett et al., 2019). Rather than increasing the quotas for every extra unit of milk demand, farmers could be encouraged to meet this margin by transitioning parcels of land to grow crops for plant-based milk. This practice would also maintain domestic supply and reduce reliance on imported non-dairy alternatives. Although probably overly ambitious under the current regime, this policy would provide an innovative way of approaching protein production.

The management of on-farm milk surpluses is a complex and multifaceted challenge that requires a coordinated and collaborative approach amongst stakeholders across the dairy industry. Farmers are responding to existing economic incentives, but these incentives produce environmental externalities and opportunity costs in the form of wasted land and water that could have otherwise produced plant-based alternatives. Although we suggest actions to reduce milk surpluses, our findings highlight the need for a broader conversation about sustainability of Canadian food systems.

The Canadian diet is very environmentally intensive (Ivanova et al., 2016), mainly due to high consumption of meat and dairy. Should the Canadian government be inducing dairy consumption via supply management when reductions are needed to foster global food system sustainability? Milk quotas provide dairy far above updated Canadian dietary guidelines and Canadians are increasingly opting for non-dairy milk with lower environmental intensity in their diets (Rochefort et al., 2023). A long-term strategy aligned with these trends would be to sustainably downscale production, without inducing demand or harming farmers in the meantime. During such a phase shift, surplus milk could be exported, although this is currently not allowed (Carter and Mérel, 2016), and would risk a rebound effect if dairy farmers start producing for export. Regardless of future changes, the Canadian dairy industry and the impacts of the DSMS need reappraisal, as there is the equivalent of 47–104 thousand dairy cattle penned up and forced to produce milk that nobody is drinking.

The findings of this study, while rooted in the Canadian context, have broader implications for the global dairy industry. The challenges associated with surplus milk production, resource wastage, and environmental impacts are not unique to Canada. As countries worldwide strive to balance food production with environmental sustainability, the lessons learned from Canada's DSMS offers valuable insights.

Globally, the need to reduce dairy waste is imperative to meet environmental targets and improve resource efficiency. This study suggests several reforms that could have universal appeal, such as enhancing transparency in milk production, incentivizing waste reduction, and reevaluating quota systems to better align with current market demands and environmental goals. For instance, adopting practices like those proposed for Canada—such as penalizing overproduction more heavily than underproduction, and incentivizing the substitution of diary milk by environmentally less burdensome plant-based alternatives—could be adapted by other nations to manage their dairy outputs more sustainably.

CRediT authorship contribution statement

Thomas Elliot: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Benjamin Goldstein:** Writing – review & editing, Writing – original draft, Visualization, Conceptualization. **Sylvain Charlebois:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data sources are provided in the Supplementary Information. In addition, we will publish the datasets on the Zenodo repository with a DOI linked in the manuscript, upon acceptance.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2024.108413.

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