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ENVIRONMENTAL IMPACT ASSESSMENT OF CHEESE PRODUCTION: A SYSTEMATIC REVIEW OF LIFE CYCLE ASSESSMENT STUDIES

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Abstract

Life Cycle Assessment (LCA) research on cheese manufacturing is increasingly embracing a wider perspective and standardized approaches. Numerous studies indicate a transition from limited gate-to-gate evaluations to comprehensive life cycle analyses (either cradle-to-grave or cradle-to-retail), particularly highlighting traditional and Protected Designation of Origin (PDO) cheeses in countries like Italy, Brazil, and the United States. The choice of allocation method significantly influences these results, with studies showing climate change impacts varying from 6 to 13 kg CO2 equivalents per kg of cheese depending on the allocation approach. Common allocation methods include dry matter content, economic value, and nutritional content, with some studies showing impact variations of up to 64% between methods. Twenty analyses evaluate the impacts of climate change, with milk production contributing to 93.5-99.6% of total impacts in certain instances. Approximately 28.3% of the climate change impacts arise from processing activities (due to energy consumption), while transport contributes 22.5%. Eutrophication and acidification are also significant factors, along with evaluations of water usage, air quality, toxicity, and resource depletion.

Introduction

Cheese is a dairy product traditionally derived from the milk of mammals, predominantly cattle. Given its favorable nutritional profile and its established role in human diets across cultures, global cheese production is expected to continue its upward trend in the coming years. This growth reflects both the enduring popularity of cheese as a versatile food and the evolving dietary preferences of consumers worldwide (Soares et al., 2021). According to the Food and Agriculture Organization (FAO), global dairy trade stabilized in 2024 at approximately 85 million tonnes, following two consecutive years of decline. This steady growth underscores the resilience of global demand for cheese, even amid ongoing economic uncertainties. The increase in cheese exports appears to be driven not only by improved production conditions but also by producers' ability to adapt to the diverse preferences and expectations of international markets (Dairy Market Review. Overview of Global Market Developments in 2024)

Materials and Methods

Twenty-five studies were analyzed on the life cycle assessment of different types of cheese from several geographical areas. Aspects of geographical and operational scope, environmental impact categories, environmental hotspots and allocation methods have been considered. A key aspect of the research is its specificity to cheese production, rather than a broader assessment of milk production or the general dairy industry. Moreover, the primary focus remains on environmental assessment rather than economic, social, or product quality aspects, ensuring a comprehensive evaluation of the ecological footprint of cheese production.

Results and Discussion

Characteristics of Included Studies

Among the 25 studies analyzed, 17 were dedicated to specific cheese varieties, 7 addressed cheese production and processing in a general context, and 1 study examined dairy products in a more comprehensive manner. Geographically, Italy emerged as the most frequently researched region, with 10 studies, followed by Brazil and the United States, each with 3 studies, and France and New Zealand, with 2 studies each. Regarding the scope of LCA, the predominant approach was cradle-to-gate, utilized in 6 studies, while cradle-to-grave and cradle-to-retail were each applied in 3 studies. Other scopes included cradle-to-consumer and farm-to-plant, along with various additional methodologies. It is noteworthy that 5 studies did not provide explicit information concerning their LCA scope.

Allocation methods

Allocation method(s)	Note	Source
Multiple methods: subdivision, allocation ratios (total solids, nutritional content, economic value)	Combination method preferred for accuracy	(H. A. Aguirre-Villegas et al., 2012)
Dry matter content, economic value, nutritive value	Results varied: 10.3 kg CO_2 eq (dry matter), 16.9 kg CO_2 eq (economic), 15.2 kg CO_2 eq (nutritive)	(Bava et al., 2018)
Mass balance based on dry matter content	Used for cheese/whey allocation	(Borghesi et al., 2022)
Substitution method	Based on nutritional content; whey considered as "fodder avoided"	(Canellada et al., 2018)
Dry matter basis	No sensitivity analyses mentioned	(Cortesi, Dijoux, Bris, et al., 2022)
Economic allocation	Used for raw milk, materials, and energy flows	(Dalla Riva et al., 2017)
Economic value, dry matter	Strong effect on impacts reported	(Gislon et al., 2023)
Mass of milk solids, revenue-based	Including plant-level engineering assessments	(D. Kim et al., 2013)
Biophysical method (IDF), Physical method (dry matter)	Different methods for farm and factory level	(Lovarelli et al., 2022)
Multiple methods: milk solids, economic, fat and protein content, no-allocation	Climate change impacts ranged 6-13 kg CO_2 eq/kg	(Riva, 2017)
Economic allocation	Factor: 0.87 for cheese, 0.13 for other outputs	(Verduna et al., 2020)

Diversification of Impact Categories

The impact categories most frequently assessed include climate change (20 studies), eutrophication (19 studies), acidification (12 studies), and water-related impacts (11 studies). Moreover, air quality, toxicity, land use, resource depletion, and ozone depletion have been examined in multiple studies. Additionally, specialized categories, including biodiversity loss, photochemical oxidant formation, ionizing radiation, and particulate matter formation, have emerged in recent research.

Evolution of Life Cycle Assessment (LCA) Methodologies

Time period	Key methodological advances	Impact categories	Standards Used
2003-2013	Focus on global warming potential, eutrophication, acidification	Limited range of impact categories	ISO 14040/14044
2014-2018	Inclusion of water use, land use, resource depletion	Expanded range of impact categories	ISO 14040/14044, ReCiPe Midpoint method
2019-2024	Integration of cumulative exergy demand, more comprehensive impact assessments	Wide range including human health, ecosystem quality	Product Environmental Footprint (PEF) method

Environmental Impact Analysis

Production phase	Primary impacts	Range of values	Key contributors
Milk Production	Climate change, Land use, Water use, Eutrophication	6.2-17.5 kg CO_2 eq/kg cheese, 93.5-99.6% of total impact	Enteric fermentation, Manure management, Feed production
Cheese Processing	Energy use, Water consumption, Wastewater generation	7.1-19 MJ/kg cheese, 28.3% of climate change impact	Pasteurization, Refrigeration, Cleaning processes
Packaging	Land occupation, Resource depletion	No mention found in most studies	Material production, Disposal
Transportation	Climate change, Photochemical oxidant formation	22.5% of climate change impact	Fuel consumption, Distance traveled
Whey Management	Potential impact reduction	Up to 1.7 kg CO_2 eq/kg cheese reduction	Whey utilization as animal feed or other products

Conclusions

Research on Life Cycle Assessment (LCA) within the cheese industry has undergone significant evolution, demonstrating an increasing focus on specificity, comprehensiveness, and broader environmental considerations. There has been a heightened emphasis on specific cheese varieties, particularly those designated with Protected Designation of Origin (PDO) status, which underscores the distinctive production processes and regional influences that affect environmental impact. The geographic scope of studies has broadened to include a more diverse array of cheese-producing regions across the globe.

The reviewed studies suggest a trend towards more comprehensive, standardized and context-specific assessments in LCAs for cheese production.

The diversity of allocation methods observed in the literature highlights the complexity of environmental impact assessment in cheese production. Future research would benefit from continued development of standardized allocation approaches that can accommodate the unique characteristics of different cheese production systems while maintaining comparability across studies