meat technology
Founder and publisher:
Institute of Meat Hygiene and Technology, Belgrade

UDK: 637.3:502.131.1
504.5
ID: 169247497
https://doi.org/10.18485/meattech.2025.66.1.7

Original Scientific Paper

Assessing the carbon footprint of cheese production: A study on mass and nutritional indicators

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ARTICLE INFO

Keywords:
Carbon footprint
Nutrition
Cheese
Dairy
Green skills

ABSTRACT

Cheese production involves various processes, with milk production contributing over 85% of the overall environmental impact. This study used a simplified life cycle assessment to estimate the carbon footprint of 13 cheese varieties based on milk quantity (1 L of raw cow milk emits 1 kg CO2e). Results were presented in relation to cheese mass and nutritional values (protein, fat, energy). Related to cheese mass, Parmesan had the highest carbon footprint (16.40 kg CO2e/kg), which correlated to milk quantity. However, when nutritional values were used as functional units, ricotta showed the highest carbon footprint for protein (88.62 kg CO2e/kg), and cottage cheese for fat (157.18 kg CO2e/kg) and energy (1.48 kg CO2e/1000 kJ). Spearman correlation coefficients for carbon footprint confirmed the correlations between the nutritional values ($p<0.05$), but no correlation was found between carbon footprint and cheese mass ($p>0.05$). Promoting nutritional values as functional units could encourage consumer alignment of dietary choices with sustainability goals.

1. Introduction

Food life cycle assessment (LCA) studies have traditionally used mass- or volume-based functional units (FUs) for expressing measured environmental impacts (*Djekic, Pojić, et al.*, 2019). However, recent research has increasingly assessed both nutritional and environmental dimensions simultaneously, thereby highlighting nutritional LCA (n-LCA) as a promising direction (*Green, Nemecek, & Mathys*, 2023). The choice between standard LCA and n-LCA is currently the subject of intense debate.

Carbon footprint, often one of the key metrics calculated within an LCA, is mainly associated with the emission of greenhouse gasses, and is expressed through measuring the global warming potential (GWP) (*ISO*, 2018).

Using mass as the FU for calculating the carbon footprint leads to a simple interpretation, but does not capture nutrition. The advantage of using protein content as a FU is the ability to simplify environmental impact comparisons between products with high nutritional value, such as cheese, and dairy alternatives, such as tofu. Energy content, which is commonly used in nutrition science to calculate dietary guidelines, can help connect issues related to obesity and overconsumption with the environmental impact. As defined in ISO 14040, (*ISO*, 2006), and highlighted by *McLaren et al.* (2021), the selection of a FU depends on the specific purpose and scope of the study.

Different cheese types differ greatly in the amount of milk used for their production, which is measured in terms of cheese yield (*Hill & Ferrer*, 2021), but also in terms of the cheeses' nutritional values (*O'Brien & O'Connor*, 2004). Europe is the world's largest cheese producer, with cheese being the most widely produced dairy product. Since the abolition of the milk quota system in 2015, the production of cheese has been steadily

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Paper received: August 30th 2024. Paper accepted January 1st 2025.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia.

increasing (*Finnegan, Yan, Holden, & Goggins*, 2018). In line with this expanding cheese production, it is crucial to study the associated environmental impacts.

Up to now, the environmental impact of cheese production has been assessed through various case studies, such as mozzarella cheese production (*Palmieri, Forleo, & Salimei*, 2017), Romanian sheep cheese production (*Ghinea & Leahu*, 2023) or LCA of different dairy products, including cheese, in Serbia (*Djekic, Miocinovic, Tomasevic, Smigic, & Tomic*, 2014).

There is also increasing data on the carbon footprint of cheese production as calculated using nutritional indicators as FUs, exemplified by the study on mature Gouda (*McLaren et al.*, 2021). In cheese production, considering the process from cradle to factory gate, milk production is the most significant contributor to GWP (79–95%), followed by the acidification potential (88–99%), and eutrophication potential (59–99%) (*Finnegan et al.*, 2018).

Considering the fact that the volume of raw milk required for cheese production differs greatly with the type of cheese, from 5.3 kg/kg of fromage frais (*Domagała et al.*, 2020) to 16.4 kg/kg of Parmesan (*Hill & Ferrer*, 2021), the aim of this study was to investigate the impact of five different FUs, i.e., both nutritional and mass-based parameters, on the calculated carbon footprint of a wide range of cheese varieties.

It is evident that there is no single FU meant to be universally applied. Each FU presents distinct benefits and drawbacks in the interpretation of the cheese's environmental impact. By presenting and analyzing the carbon footprints based on various FUs and various cheese types, we aim to provide a comprehensive carbon footprint matrix that can inform future LCA studies and guide decision-making in the cheese production and consumption segment.

2. Materials and Methods

The main LCA stages are defined by the international standard for this type of study (*ISO*, 2006). For the purpose of this study, a partial, simplified LCA was employed, applying the following criteria: (i) the goal of this LCA was to calculate and compare carbon footprint of 13 types of cheese; (ii) FUs used to express the carbon footprint were mass (kg) and four nutritional values (protein, fat, energy and calcium); (iii) inventory analysis of raw milk production was based on calculation that included the quantity of milk used for cheese production; (iv) impact assessment covered only one environmental impact, i.e, the GWP; (iv) the interpretation focused on understanding how the quantity of milk affects the calculation of the cheese's carbon footprint when different FUs are used.

Table 1. Quality parameters of 13 different cheese types

Cheese type	Yield (kg milk/kg cheese)	Total solids (%)[a]	Protein (%)[a]	Fat (%) [a]	Calcium (mg/100g)[f]	Energy	
						kcal[a]	kJ[a]
Brie	7.1[e]	51.4	19.3	26.9	540	319	1,323
Camembert	6.8[e]	49.3	20.9	23.7	350	297	1,232
Cheddar	10.0[e]	64.0	25.5	34.4	720	412	1,708
Cottage	6.1[c]	20.9	13.8	3.9	73	98	413
Edam	11.5[e]	56.2	26.0	25.4	770	333	1,382
Emmental	11.0[e]	64.3	28.7	29.7	970	382	1,587
Feta	7.1[e]	43.5	15.6	20.2	360	250	1,037
Fromage frais	5.3[d]	22.3	6.8	7.1	89	113	469
Gouda	10.3[e]	59.9	24.0	31.0	740	375	1,555
Gruyere	11.5[e]	65.0	27.2	33.3	950	409	1,695
Mozzarella	9.0[e]	50.2	25.1	21.0	590	289	1,204
Parmesan	16.4[e]	81.6	39.4	32.7	1,200	452	1,880
Ricotta	8.3[b]	27.9	9.4	11.0	240	144	599

Source of data: [a] (*O'Brien & O'Connor*, 2004), [b] (*Ortiz Araque, Darré, Ortiz, Massolo, & Vicente*, 2018) [c] (*Klei, et al.*, 1998) [d] (*Domagała, et al.*, 2020) [e] (*Hill & Ferrer*, 2021) [f] (*O'Brien & O'Connor*, 2004)

For the purpose of this study, it was assumed that 1 kg of CO_2 is emitted into the atmosphere for each kg of raw milk produced, as proposed in the literature (*IDF*, 2009, 2023). Table 1 shows the quality parameters of 13 different cheese types. Data were extracted from literature sources (*Domagała et al.*, 2020; *Hill & Ferrer*, 2021; *Klei et al.*, 1998; *O'Brien & O'Connor*, 2004; *Ortiz Araque, Darré, Ortiz, Massolo, & Vicente*, 2018)

The impact of processing factors (such as energy or water) for cheese production are below 5%, as outlined in LCA databases (*openLCA*, 2024), and were not considered in this calculation.

The Spearman rank order correlation coefficient (rs) was calculated to measure the correlation between the carbon footprints of the 13 different types of cheese expressed in the selected FUs.

3. Results and Discussion

The findings revealed that presenting the carbon footprint as kg CO_{2e}/kg of cheese highlighted Parmesan as the cheese having the highest carbon footprint (16.40 kg CO_{2e}/kg of cheese). In general, as a result of the simplified calculation of GWP, the environmental impact of cheese production using cheese mass as a FU is directly correlated with the quantity of cheese milk. However, employing nutritional values as FUs revealed that among the 13 cheeses, ricotta exhibited the highest carbon footprint when it comes to protein (88.62 kg CO_{2e}/kg of protein), while cottage cheese had the highest GWP related to both fat content and energy (157.18 kg CO_{2e}/kg of fat and 1.48 kg CO_{2e}/1000 kJ, respectively) (Table 2).

In the study by *Katz-Rosene, Ortenzi, McAuliffe, and Beal* (2023) the term "cheese" was used in the context of LCA. However, the present study suggests that greater precision in defining "cheese" could improve the clarity and accuracy of such evaluations, given the considerable variation in the carbon footprints among the different types of cheese, especially when combined with the various FUs (Table 2).

According to the literature in which mass indicators were used as the FU, fresh cheeses could have lower environmental impacts than do semi-hard or hard cheeses (*Finnegan et al.*, 2018). However, the current study reveals that when protein content is considered as the FU, the GWP of fromage frais or ricotta is nearly double that of Edam or Gouda. This difference is even more pronounced when calcium content is considered as the FU. For instance, in that case, the GWP of cottage cheese is up to seven times higher than that of Gruyere (Table 2).

When GWP is calculated in relation to mass as a FU, a boundary was set (*Röös, Ekelund, & Tjärnemo*, 2014) at the threshold at 4 kg CO_{2e} for the transition from green to yellow label. The next

Table 2. Carbon footprint of different types of cheeses expressed in different functional units

Cheese type	kg CO_{2e}/ kg cheese	kg CO_{2e}/ 1 kg protein	kg CO_{2e}/ 1 kg fat	kg CO_{2e}/ 1000 KJ	kg CO_{2e}/ 1000 mg Ca)
Brie	7.10	36.79	26.39	0.54	1.31
Camembert	6.80	32.54	28.69	0.55	1.94
Cheddar	10.10	39.61	29.36	0.59	1.40
Cottage cheese	6.13	44.42	157.18	1.48	8.40
Edam	11.50	44.23	45.28	0.83	1.49
Emmental	11.00	38.33	37.04	0.69	1.13
Feta	7.10	45.51	35.15	0.68	1.97
Fromage frais	5.32	78.24	74.93	1.13	5.98
Gouda	10.30	42.92	33.23	0.66	1.39
Gruyere	11.50	42.28	34.53	0.68	1.21
Mozzarella	9.00	35.86	42.86	0.75	1.53
Parmesan	16.40	41.62	50.15	0.87	1.37
Ricotta	8.33	88.62	75.73	1.39	3.47

Table 3. Spearman's Rho correlation coefficient between carbon footprints of different types of cheese expressed in five functional units

Different functional units	Cheese mass	Protein	Fat	Energy	Calcium
Cheese mass	1.000	−0.182	−0.074	−0.055	−0.733**
Protein	−0.182	1.000	0.654*	0.644*	0.544
Fat	−0.074	0.654*	1.000	0.999**	0.544
Energy	−0.055	0.644*	0.999**	1.000	0.523
Calcium	−0.733**	0.544	0.544	0.523	1.000

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

threshold was set at 14 kg CO_{2e} as a transition from yellow to red. *Rysselberge and Röös* (2021) reported that all cheeses fall within the yellow range. The current study confirms these data, with the exception of Parmesan, which was in the red range. In parallel, all protein-rich products, such as lentils, dry soybeans, and tofu, are consistently in the green range, i.e., below the 4 kg CO_{2e} threshold, when assessed via the mass indicator approach. Based on this idea, it can be claimed that all types of cheese have a higher negative impact on the environment and carbon footprint than plant-based alternatives (*Shabir et al.*, 2023).

However, a shift to the nutrient or micronutrient approach yields contrasting results. For instance, while the global average carbon footprint of cheese stands approximately eight times higher than that of tofu per kilogram of retail weight, this difference narrows significantly to about 1.8 times when recalculated using the targeted priority micronutrient value (*Katz-Rosene et al.*, 2023). Table 3 shows the correlation of GWP with the different FUs. GWP expressed as cheese mass was correlated with GWP expressed as calcium content, while the protein-related GWP was correlated with fat- and energy-related GWP.

Despite the limited presence of carbon footprint labels in the market, it could be agreed that they play a crucial role in enabling consumers to make informed decisions that contribute to addressing climate change (*Canavari & Coderoni*, 2020). This is more pronounced when carbon footprint is calculated from the consumption perspective (*Djekic, Petrovic, Božičković, Djordjevic, & Tomasevic*, 2019). However, the modern consumer's food purchasing decisions depend also on the nutritional quality of food, and the consumer's wellness goals (*Martínez-Ruiz & Gómez-Cantó*, 2016). The current study highlights the importance of incorporating both environmental and nutritional dimensions into carbon footprint calculations. For instance, instead of consuming soft cheeses like ricotta (88.2 kg CO_{2e}/kg protein), individuals who are concerned about both their protein intake and the environment might choose Camembert (32.54 kg CO_{2e}/kg protein) or mozzarella (35.86 kg CO_{2e}/kg protein). For environmentally conscious consumers seeking high calcium content in their diet, Gruyere (1.21 kg CO_{2e}/1000 mg Ca) would be a much better choice than cottage cheese (8.40 kg CO_{2e}/1000 mg Ca).

4. Conclusion

The present study provides better understanding of the environmental impact in relation to nutritional values of cheeses for the purpose of aligning dietary preferences with sustainability goals. Promoting nutritional values as FUs facilitates informed decision-making and encourages environmentally conscious choices, contributing to a more sustainable and responsible approach to food consumption. Finally, the current study intends to combat any type of greenwashing associated with promoting "greener" cheeses by expressing only their carbon footprint per mass.

Future studies could focus on expanding the carbon footprint matrix from the current study by incorporating additional data on plant-based cheese alternatives.

Procena ugljeničnog otiska u proizvodnji sira: Studija o masenim i nutritivnim indikatorima

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APSTRAKT

Proizvodnja sira obuhvata različite procese pri čemu sama proizvodnja mleka utiče sa preko 85% u ukupnim uticajima na životnu sredinu. Ovo istraživanje je koristilo pojednostavljenu ocenu uticaja na životnu sredinu kako bi procenila ugljenični otisak 13 vrsta sireva u odnosu na utrošak mleka za njihovu proizvodnju (proizvodnja 1 L sirovog kravljeg mleka emituje 1 kg CO2e). Rezultati su prikazani u odnosu na masu sira kao i nutritivne vrednosti (proteini, masti, energija). U odnosu na masu sira, Parmezan je ima najveći ugljenični otisak (16.40 kg CO2e/kg) što je u direktnoj korelaciji sa količinom mleka. Ipak, ako su uzmu nutritivne vrednosti kao funkcionalne jedinice, Rikota je imala najveći ugljenični otisak u odnosu na proteine (88.62 kgCO2e/kg), a švapski sir u odnosu na udeo masti (157.18 kg CO2e/kg) i energetsku vrednosti (1.48 kg CO2e/1000 kJ). Spirmanog koeficijent korelacije za ugljenični otisak je potvrdio korelaciju između nutritivnih vrednosti ($p<0.05$) bez korelacije u odnosu na masu ($p>0.05$). Promovisanje nutritivnih vrednosti kao funkcionalnih jedinica ohrabruje prilagođavanje izbora u ishrani sa ciljevima održivog razvoja.

Disclosure statement: No potential conflict of interest was reported by authors.

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