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Life cycle assessment of minas frescal cheese and cured minas cheese: a comparative analysis

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Abstract

Brazil is a large producer of dairy products, with an important role of milk in the country's economy beyond the nutritional aspects. In turn, the dairy industry is associated with environmental impacts, such as water and energy consumption, waste generation, liquid effluents, and atmospheric emissions. Life Cycle Assessment (LCA) is an environmental management tool used to measure the environmental impacts of goods, services, and products. This study used the LCA to assess the impacts resulting from the production of Minas Frescal and cured Minas cheese in an artisanal production facility in Casimiro de Abreu, Rio de Janeiro, Brazil. LCA results showed that the most significant environmental impacts were associated with the dairy farm under study, which is a source of greenhouse gases (GHG) emissions from livestock, particularly methane (CH4), produced through enteric fermentation and manure decomposition, mainly contributing for the impact categories of climate change (31.56%) and human toxicity with carcinogenic effects (35.46%). The cured Minas cheese presented higher impacts when compared to Minas Frescal cheese due to the larger volume of milk used in the manufacturing process. Thus, the present study suggested mitigation measures to lower the environmental impacts based on adjustments in animal feed to reduce atmospheric emissions.

Keywords: Life Cycle Assessment; Minas Frescal cheese; cured Minas cheese; environmental impacts.

Practical Application: The Life Cycle Assessment environmental management tool was used to compare the environmental impacts of the manufacture of fresh Minas cheese and cured Minas cheese. The results showed that the greatest environmental impacts are found on dairy farms, from the enteric fermentation and the animal feed. The analysis of animal feed composition (grass, corn, sugar cane) allowed suggesting mitigation measures to reduce the environmental impacts by using a larger amount of grass in the animal feed, for example.

1 Introduction

Brazil is a major milk producer in the world, with great social importance in generating rural jobs and income (Rocha et al., 2021). According to the Food and Agriculture Organization of the United Nations (2021), Brazil is the world's third largest milk producer, behind the United States and India. The country's milk production is likely to rise by 1.0% per year due to increasing dairy cow numbers, higher herd sizes, improved genetics, and high yields in large-scale farms (Food and Agriculture Organization of the United Nations, 2019).

According to the 2021 Empresa Brasileira de Pesquisa Agropecuária (2021) yearbook, milk production in Brazil averaged 35 million liters in 2020. Cow's milk is one of the most consumed products in the world. It has high nutrition value, easy acceptance, with great commercialization, and high yield. In Brazil, cheese also has a socioeconomic importance due to its high production and commercialization (Lopes et al., 2020; Hajmohammadi et al., 2020; Messias et al., 2022).

Cheese is among the most consumed dairy products, corresponding to 14% of the world's consumption (Siqueira & Schettino, 2021). In addition, it is associated with health benefits once it is considered a source of vitamins (A, B2 and B12), minerals (calcium and phosphorus) and proteins (Rodrigues et al., 2022). Recent studies have shown that all these nutrients together may reduce the potential risk of cardiovascular diseases (Feeney et al., 2021). According to Zhou et al. (2022), fermented cheeses contain vitamin K2, which is also associated with benefits in preventing cardiovascular health.

Minas Frescal cheese is characterized as a raw paste with whitish color and soft texture due to its high moisture content (Rodrigues, 2021). In turn, Cured Minas cheese is subjected to a ripening process with consequent water loss, leading to changes in the sensory, chemical, and biochemical characteristics of the final product (Salum et al., 2018; Carneiro et al., 2020).

Although the milk production chain is one of the most important in agribusiness, it is associated with several environmental impacts such as atmospheric emissions, high consumption of inputs, water, and energy, and generation of effluents and waste with polluting potential that contribute negatively to environmental degradation (Matricarde et al., 2021). Palmieri et al. (2016) reported that the raw milk production

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has the highest environmental impact within the dairy supply chain, contributing to the global warming, river acidification and eutrophication, especially greenhouse gas (GHG) emissions. Feil et al. (2020) reported high water consumption in dairy production, leading to the generation of a large amount of waste, effluents, and by-products. These environmental impacts can be measured through an environmental management tool known as Life Cycle Assessment (LCA).

LCA is a methodology used to identify and evaluate the environmental impacts generated by a product or service throughout its production chain, i.e., from the extraction of raw materials to the final disposal of the product (Müller et al., 2020). LCA provides a cradle-to-grave analysis, thus assessing the advantages and disadvantages of a production process (Willers et al., 2013). It is a valuable tool to analyze the interactions between direct and indirect human activities and their impact on the environment (Zocche & Francisco, 2013).

Djekic et al. (2014) used LCA to evaluate the environmental impacts of cheese production. The results showed that on-farm activities and animal feed production were the most responsible for the impacts, followed by the manufacturing, distribution, and consumption phases. Milani et al. (2011) also used LCA in milk production and reported that the on-farm milk production phase was responsible for the most significant environmental impacts. Wang et al. (2016) used LCA on a farm in Guanzhong, China, and reported that enteric methane emissions and animal feed production were the main GHG emissions generators in the life cycle of milk.

Dalla Riva et al. (2017) applied an LCA cradle-to-grave approach, from the farm activities to consumption and disposal, to assess the environmental impacts of Italian mozzarella cheese from raw milk and mozzarella obtained from the curd. The results indicated that feed production and animals enteric GHG emissions on the farm were the hot spot of environmental impacts, showing that the cheese manufactured with raw milk was more sustainable when compared to that made with curd.

Zhao et al. (2018) used the LCA tool to calculate the carbon footprint of a dairy production system associated with on-farm milk production, product processing, transportation, and packaging waste disposal. Milk production accounted for 75.27% of the emissions, while the others accounted for 15.45, 3.89, and 5.89%, respectively. The authors concluded that the carbon footprint of the dairy production system can be reduced by adjusting the proportions of animal feed.

Nunes et al. (2020) used LCA to assess the environmental impacts of Beira Baixa, regional goat cheese from Portugal and concluded that the major impacts were related to the raw milk production stage, i.e. on the farms. The percentages related to this process step were climate change (93%), land acidification (96%), and freshwater eutrophication (100%).

In Brazil, Cabral (2018) performed an LCA to analyze the environmental impacts of goat milk and goat cheese production and concluded that the major environmental impacts come predominantly from goat milk production, specifically from land use and animal feed, composed of soybean and corn concentrate, the main source of goat feed (Cabral et al., 2020). Almeida et al. (2020) used LCA approach, from gate-to-gate to evaluate the environmental impacts of the production of mozzarella cheese and reported that the greater environmental impacts were associated with the production of milk at the dairy farm, for all impact categories studied.

According to United Nations Environment Programme (2021), the agricultural sector is responsible for 40% of the world's CH_4 emissions to the atmosphere, out of which 32% represent enteric fermentation and manure decomposition emissions from livestock. In this sense, during the 26th United Nations Conference on climate change (COP 26) in 2021, the Global Methane Pledge was signed by 126 countries, which aims to reduce GHG emissions by up to 30% by the end of this decade (Chiaretti, 2021).

It is worth mentioning that in 2010 Brazil established the Low Carbon Emission in Agriculture and Livestock Sector Plan for Sustainable Development (ABC Plan), a public policy aimed at promoting the adoption of sustainable technologies by the agricultural and livestock sector with high potential for mitigating GHG emissions and combating global warming (Brasil, 2021).

Although some studies have shown animal feed at the farm level as a significant source to CH_4 emissions from enteric fermentation by dairy cattle, there are no studies using LCA to compare different feed composition scenarios in the animal diet and its effects on the reduction of CH_4 emissions.

Thus, this study aims to conduct a Life Cycle Assessment on the production of Minas Frescal cheese and cured Minas cheese in an artisanal production located at the municipality of Casimiro de Abreu, state of Rio de Janeiro, Brazil. The methodology established by ABNT NBR ISO 14040:2009 Environmental management - Life cycle assessment allowed the identification of environmental impacts at the farm level and associated with production processes, analyzing the different scenarios of animal feed, and suggesting measures to mitigate the impacts (Associação Brasileira de Normas Técnicas, 2009a). The study evaluated the composition of animal feed used in the dairy farm through four different scenarios, aimed to determine the scenario with the least environmental impact, especially concerning the category climate change, once the change in the feed mix can alter the GHG emissions from livestock, thus contributing to the reduction of CH_4.

2 Materials and methods

The Life Cycle Assessment (LCA) study was conducted in accordance with ISO 14040:2009 (Environmental Management-Life Cycle Assessment-Principles and Frameworks) and ISO 14044:2009 (Environmental Management-Life Cycle Assessment-Requirements and Guidance) (Associação Brasileira de Normas Técnicas, 2009b).

LCA is based on four interdependent phases as follows: 1) goal and scope definition, 2) inventory analysis, 3) environmental impact assessment, and 4) results interpretation. This interdependence makes this tool iterative, as usually not all data is known at the beginning of the study (Müller et al., 2020).

The first phase consisted of selecting a production plant of at least two different types of cheese to allow a comparison of life cycles. Thus, an artisanal production located in the municipality of Casimiro de Abreu (RJ) that produced both Fresh Minas cheese and cured Minas cheese was selected.

During the technical visit, it was informed that, for economic reasons, the cows were allocated to a farm in the same municipality as the dairy plant, which allowed the liter of milk for the cheese manufacture to be acquired for a lower value.

2.1 Goal and scope

After the selection of the dairy plant, the objectives of the study were defined as follows: identification and evaluation of environmental impacts associated with the production of milk and cheese, comparison of the manufacturing process of fresh and cured cheese concerning the possible environmental impacts, and suggestion of mitigation measures for the identified impacts.

One liter of milk and 1 kg of cheese were defined as the functional unit for both types of cheese, and a "cradle-to-gate" analysis was done. Figure 1 shows a scheme of the cheese-making process.

2.2 Inventory analysis

For data collection, a technical visit was made to the factory, and questions were made about milk production, waste generation, water and energy consumption, and other activities associated with cheese making, as reported by Cabral (2018). Figure 2 presents the flow of inputs and outputs of cheese production based on the primary and secondary data for the inventory analysis.

Primary data were analyzed by the software SimaPro version 8.3 to determine the impacts generated, while the secondary data were obtained using the Ecoinvent life cycle inventory database version 3.0.

2.3 Impact assessment

To identify the stage of cheese manufacture with the greatest environmental impact, the methodology from the ILCD Handbook: Analysis of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment (European Comission, 2010) was used. Therefore, the following categories of environmental impacts were analyzed: climate change, ozone depletion, human toxicity (not including cancer), human toxicity (cancer), particulate matter, HH (Human Health) ionizing radiation, E ionizing radiation, photochemical ozone formation, acidification, terrestrial eutrophication, water eutrophication, marine eutrophication, water ecotoxicity, land use, water depletion, and mineral, fossil, and renewable resource depletion. The impacts derived from facilities, construction, and transportation of raw material to the processing plant, manufacturing, and maintenance of equipment and utensils were not considered in this study.

2.4 Proposed scenarios

Based on the animal feed used in the dairy farm, which was composed of a mixture of grass, sugarcane, and corn (baseline scenario), three other possible feeding scenarios were proposed (Table 1). The objective of this change was to evaluate the compositions of the feed mix with less impact on the environment, contributing to the reduction of GHG emissions, mainly CH4 emissions.

Whereas ruminant feed is closely related to greenhouse gas (GHG) emissions, the scenarios were evaluated to establish a possible reduction of environmental impacts generated by the change in feed composition.

2.5 Interpretation of results

The results were aligned with the goals defined in the initial LCA study. Therefore, it was possible to draw conclusions and suggest mitigating measures for the environmental impacts identified.

3 Results and discussion

The analysis of the impact categories and the present results showed that the largest contributors to environmental impacts

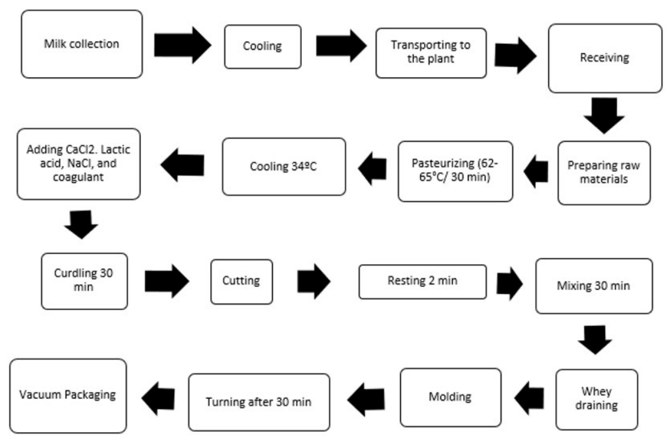


Figure 1. Flowchart of the cheese production process. Source: the author, according to the information from the producer (2021), adapted by Venturini et al. (2007).

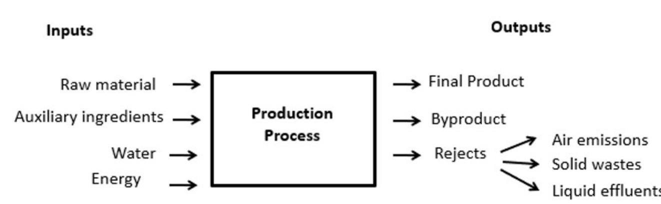


Figure 2. Inputs and outputs of the cheese production process. Source: The author.

Table 1. Different scenarios proposed for the feed mix.

Components	Baseline Scenario	Scenario 1	Scenario 2	Scenario 3
Grass	5 kg	15 kg	10 kg	10 kg
Sugar Cane	10 kg	10 kg	5 kg	10 kg
Corn	15 kg	5 kg	15 kg	10 kg

Source: The author.

arise from dairy production on the dairy farm. Graph 1 presents the LCA results for the production of 1L of milk for the impact categories studied using the methodology ILCD MidPoint.

The categories climate change and human toxicity (with carcinogenic effects) were the most significant for milk production (1L), accounting for 31.56 and 35.46% of the total environmental impacts generated, respectively. GHG emissions contribute significantly to climate change, and methane gas (CH4) and nitrous oxide (NO2) are the main GHGs associated with milk production (Cruz, 2020; Nunes, 2018) due to the presence of CH4 in the enteric fermentation of animals and their manure, while NO2 is found in synthetic fertilizers and animal urine (Martins-Costa, 2015; Basset-Mens et al., 2009). In the present study, the percentage of 31.56% of climate change was associated with the enteric fermentation in the rumen of the animals, their manure and urine. It is worth mentioning that this herd had 210 animals in extensive livestock farming, and a formulation based on nitrogen, phosphorus, and potassium was used for soil fertilization.

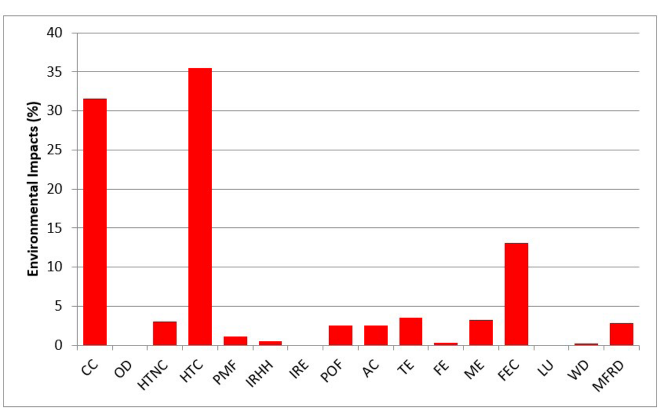
In this context, Almeida et al. (2020) stated that the greatest environmental impacts were associated with the milk production on the dairy farm. The authors reported that climate change also showed great relevance with a percentage of 83%, derived mainly from enteric fermentation and manure management, and the application of synthetic fertilizers on pastures and urine to a lesser extent. Thus, after identifying the most significant impact categories in the production of 1L of milk, LCA was performed comparing the environmental impacts associated with Minas Frescal cheese and Cured Minas cheese, both produced at the dairy, as shown in Graph 2.

As can be seen in, Graph 2, the environmental impacts were proportional to the types of cheese. Considering that the greatest environmental impacts were associated with the dairy farm, the cheese made with a greater volume of milk (cured cheese) contributed more significantly to the impact generation. Based on primary data, Minas Frescal cheese used 4.81 L of milk to produce 1 kg of cheese, while the cured Minas cheese required 7.54 L of milk, thus generating greater environmental impacts due to the higher volume of milk used for cheese making. It is worth noting that the dairy used a lower volume of milk to produce 1 kg of cheese when compared to other studies in the literature. Gonçalves (2017) estimated an average of 10 liters of milk to produce 1 kg of cheese, of which 9 L corresponded to the volume of whey generated during cheese manufacture. According to Cassoli (2013), the changes in yield may be due to the milk composition, as higher casein content provides a greater amount of cheese produced per liter of milk.

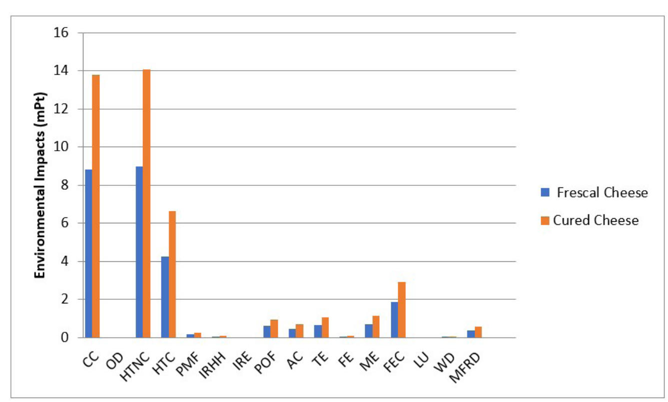
When analyzing the four different scenarios (baseline scenario and three proposed scenarios) for the feed mix used for cattle feed, the base scenario, scenario 2, and scenario 3 surpassed the scenario 1 concerning the total impacts. Graph 3 presents the LCA results for the 4 scenarios considered for the feed mix.

The base scenario and scenario 2 have a higher water ecotoxicity (13.17 and 12.41%, respectively) once they contain a higher amount of corn in the formulation. In contrast, the percentages of climate change were lower when compared to the other scenarios (31.64 and 29.72%, respectively).

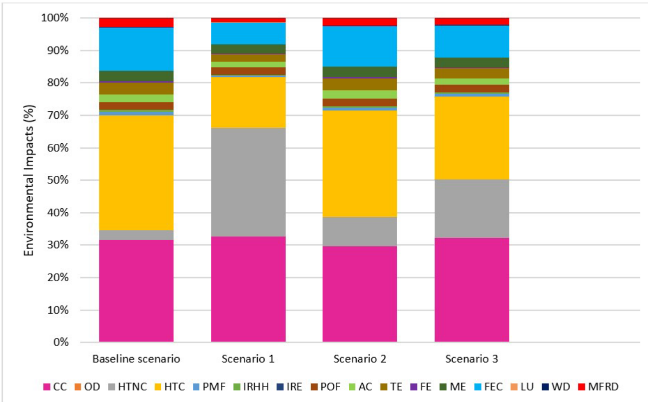
When comparing the four scenarios, the greatest difference was observed for the category human toxicity without carcinogenic effects, with the highest percentage (33.29%) for scenario 1. As it contains a greater amount of grass in the composition, this discrepancy in values may be due to fertilization and the ammonia nitrogen from the soil. In turn, the baseline scenario and scenario 3 showed the highest human toxicity values with carcinogenic effects, with percentages of 35.47 and 32.81%, respectively.



Graph 1. Impact assessment of cow's milk for baseline scenario as a percentage of total impact (ILCD Mid Point). Legend: CC (Climate Change); OD (ozone depletion); HTNC (human toxicity non- cancer); HTC (human toxicity cancer); PMF (particulate matter formation); IRHH (ionizing radiation HH); IRE (ionizing radiation E); POF (photochemical oxidant formation); AC (acidification); TE (terrestrial eutrophication); FE (freshwater eutrophication); ME (marine eutrophication); FEC (Freshwater ecotoxicity); LU (land use); WD (water depletion); MFRD (mineral, fossil and renewable resources depletion). Source: Elaborated by the author.



Graph 2. Environmental impact assessment for frescal and cured cheese in the baseline scenario (ILCD MidPoint). Legend: CC (Climate Change); OD (ozone depletion); HTNC (human toxicity non- cancer); HTC (human toxicity cancer); PMF (particulate matter formation); IRHH (ionizing radiation HH); IRE (ionizing radiation E); POF (photochemical oxidant formation); AC (acidification); TE (terrestrial eutrophication); FE (freshwater eutrophication); ME (marine eutrophication); FEC (Freshwater ecotoxicity); LU (land use); WD (water depletion); MFRD (mineral, fossil and renewable resources depletion). Source: Elaborated by the author.



Graph 3. Impact percentage for the 4 different scenarios of cattle feed composition. (ILCD MidPoint). Legend: CC (Climate Change); OD (ozone depletion); HTNC (human toxicity Non- cancer); HTC (human toxicity cancer); PMF (particulate matter formation); IRHH (ionizing radiation HH); IRE (ionizing radiation E); POF (photochemical oxidant formation); AC (acidification); TE (terrestrial eutrophication); FE (freshwater eutrophication); ME (marine eutrophication); FE (Freshwater ecotoxicity); LU (land use); WD (water depletion); MFRD (mineral, fossil and renewable resources depletion). Source: Elaborated by the author.

Thus, it was evident that the changes in animal feed can contribute to the reduction of environmental impacts in the different categories. However, the baseline scenario, scenario 2, and scenario 3 presented higher impacts when compared to scenario 1 regarding the total impacts.

The nutrition of ruminants is closely related to GHG emissions, thus the greater ease of digestion of feed components can lead to higher emissions from enteric fermentation (Carvalho, 2016). Good nutrition improves the effects of fermentation, causing a reduction in the amount of hydrogen available for CH4 production (Brasil, 2017). Therefore, the use of a feed mix composed of 15 kg of grass, 10 kg of sugarcane, and 5 kg of corn (scenario 1) can contribute to mitigating the environmental impacts generated on the dairy farm of this study.

Furthermore, based on the literature and the present results, other actions can be taken to mitigate the environmental impacts associated with the artisanal production of Minas Frescal cheese and cured Minas cheese, with a focus on reducing emissions.

The French dairy industry created the program "fermes bas carbone" (low carbon farms) in 2019, aimed at reducing GHGs emissions by 20% by 2025 through the replacement of soybean meal with canola meal in animal feed, as well as use of organic fertilizers to prevent ammonia volatilization (Exame, 2019). Roque et al. (2021) reported that the addition of red algae to animal feed reduced methane emissions, leading to a decrease in environmental damage.

Precision nutrition is a technique used to produce a balanced diet for animals, taking into account technical, economic, and environmental factors, in addition to providing balanced nutrients according to the animal's needs. It also prevents excessive feeding, reducing costs and animal excretion that generate increased emissions (Brasil, 2017, Tomich et al., 2015).

Beltrão et al. (2022) studied the physicochemical profile of goat milk after replacing corn in animal feed, which is a major contributor of GHG emission, with flaxseed oil. The authors reported a variation in the lipid profile of milk, which showed higher unsaturated fatty acids and lower saturated fatty acids levels, thus providing health benefits. A slight variation in pH and color of the product was also observed by the authors.

Another promising alternative to mitigate atmospheric emissions has been studied by the European dairy cooperative Arla Foods and Royal DSM, through a feed additive capable of reducing about 30% of CH4 emissions acting in the enteric fermentation of animals (MilkPoint, 2022). Thus, several measures can be adopted to reduce enteric fermentation of animals and consequently mitigate GHG emissions, mainly methane.

4 Conclusion

This study used the LCA tool to analyze the environmental impacts associated with small-scale production of Minas Frescal cheese and cured Minas cheese. The analysis of different scenarios of animal feeding was also performed to reduce the impacts generated, especially CH4 emissions from enteric fermentation.

The use of the LCA tool to support the decision-making in the reduction of emissions should be emphasized and recommended to identify the relevant environmental impacts and select the technological alternatives to improve the sustainability of the dairy sector.

The present study identified milk farm as a source of the greatest environmental impacts associated with the production of artisanal Minas Frescal cheese and Cured Minas cheese. The impact categories with the highest representativeness were climate change and human toxicity (with carcinogenic effects) representing 31.56 and 35.46%, respectively. Once the most relevant impacts were associated with milk production (farms), cured Minas cheese was responsible for a greater generation of environmental impacts when compared to Minas Frescal cheese, due to the larger volume of milk required for its production.

Four different scenarios were proposed for the feed mixt used for feeding animals on the dairy farm aimed to determine the composition with lower environmental impacts. The scenario 1 composed of a mix of 15 kg of grass, 10 kg of sugar cane, and 5 kg of corn presented a lower total impact when compared to the other scenarios. Therefore, the environmental impacts can be reduced with the adoption of this composition for cattle feeding

Based on LCA of the present study and literature data, mitigating measures can be used to reduce the relevant environmental impacts, with an emphasis on adjustments in animal feed to reduce atmospheric emissions, such as the insertion of red algae in the feed formulation, precision nutrition, and feed additives capable of reducing atmospheric emissions from enteric fermentation. Thus, the production chain becomes more sustainable, less harmful to the environment, and potentially more economically advantageous for the producer. It is worth emphasizing that further studies are required to identify the environmental impacts associated with the different feedstuffs used in animal feed.

References

Almeida, G. F. A. Fo., Bitencourt, E. B., Ferreira, E. C., Oliveira, V. S., & Loureiro, G. E. (2020). Avaliação do ciclo de vida do queijo muçarela de um laticínio na região norte do Brasil. *Revista Científica Eletrônica de Engenharia de Produção*, 20(1), 316-339. http://dx.doi.org/10.14488/1676-1901.v20i1.3614.

Associação Brasileira de Normas Técnicas – ABNT. (2009a). *ABNT NBR 14040:2009: gestão ambiental- avaliação do ciclo de vida- princípios e estrutura.* Rio de Janeiro.

Associação Brasileira de Normas Técnicas – ABNT. (2009b). *ABNT NBR 14044:2009: gestão ambiental - avaliação do ciclo de vida - requisitos e orientações.* Rio de Janeiro.

Basset-Mens, C., Ledgard, S., & Boyes, M. (2009). Eco-efficiency of intensification scenarios for milk production in New Zealand. *Ecological Economics*, 68(6), 1615-1625. http://dx.doi.org/10.1016/j.ecolecon.2007.11.017.

Beltrão, L. G. C., Cruz, G. C. B., Souza, D., Sant'Ana, A. M. S., Fonseca, S. B., Salviano, G. O., Ribeiro, N. L., & Andrade, R. O. (2022). Physicochemical profile of milk and cheese of goat feed with flashseed oil substituting the corn. *Food Science and Technology*, 42, 1-9. http://dx.doi.org/10.1590/fst.94821.

Brasil, Ministério da Agricultura, Pecuária e Abastecimento – MAPA. (2017). *Pecuária de baixa emissão de carbono: tecnologias de produção mais limpa e aproveitamento econômico dos resíduos da produção de bovinos de corte e leite em sistemas confinados* (1ª ed.). Brasilia: MAPA.

Brasil, Ministério da Agricultura, Pecuária e Abastecimento – MAPA, Secretaria de Inovação, Desenvolvimento e Irrigação. (2021). *Plano setorial para adaptação à mudança do clima e baixa emissão de carbono na agropecuária com vistas ao desenvolvimento sustentável (2020-2030): visão estratégica para um novo ciclo.* Brasilia: MAPA.

Cabral, C. F. S., Elabras-Veiga, L. B., Araújo, M. G., Souza, S. L. Q. (2020). Environmental Life Cycle Assessment of goat cheese production in Brazil: a path towards sustainability. *LWT - Food Science and Technology*, 129, 109550. http://dx.doi.org/10.1016/j.lwt.2020.109550.

Cabral, C.F. S. (2018). *Avaliação do ciclo de vida na produção industrial de queijo de cabra* (Dissertação de mestrado). Instituto Federal de Educação, Ciência e Tecnologia, Rio de Janeiro.

Carneiro, J. O., Chaves, A. C. S. D., Stephan, M. P., Boari, C. A., & Koblitz, M. G. B. (2020). Artisan Minas Cheese of Serro: proteolysis durinh ripening. *Heliyon*, 6(7), 1-7. http://dx.doi.org/10.1016/j.heliyon.2020.e04446.

Carvalho, L. S. (2016). *Impactos ambientais do leite produzido no território de identidade médio sudoeste da Bahia* (Dissertação de mestrado). Universidade Estadual do Sudoeste da Bahia, Itapetinga. Retrieved from http://www2.uesb.br/ppg/ppgca/wpcontent/uploads/2017/11/Disserta%C3%A7%C3%A3o_Laurine_PPGCA_2016.pdf

Cassoli, L. D. (2013). *Qual a importância do leite para a qualidade dos queijos?* Milkpoint. Retrieved from https://www.milkpoint.com.br/colunas/clinica-do-leite/producao-de-queijo-qual-a-importancia-da-qualidade-do-leite-205226n.aspx

Chiaretti, D. (2021, November 3). Brasil aderiu a compromisso sobre metano na COP26 por pressão dos EUA. *Jornal O Globo*.

Cruz, G. M. (2020). *Emissões de GEE na pecuária de leite brasileira: custo marginal de abatimento para diferentes sistemas de produção e implicações políticas* (Dissertação de mestrado). Universidade de São Paulo, Piracicaba.

Dalla Riva, A., Burek, J., Kim, D., Thoma, G., Cassandro, M., & Marchi, M. (2017). Environmental life cycle assessment of Italian mozzarella cheese: hotspots and improvement opportunities. *Journal of Dairy Science*, 100(10), 7933-7952. https://doi.org/10.3168/jds.2016-12396.

Djekic, I., Miocinovic, J., Tomasevic, I., Smigic, N., & Tomic, N. (2014). Environmental life-cycle assessment of various dairy products. *Journal of Cleaner Production*, 68, 64-72. http://dx.doi.org/10.1016/j.jclepro.2013.12.054.

Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA. (2021, April 3). *Pesquisa demonstra que manejo adequado de bovinos reduz emissões de metano*. Retrieved from https://www.embrapa.br/busca-de-noticias/-/noticia/32934505/pesquisa-demonstra-que-manejo-adequado-de-bovinos-reduz-emissoes-de-metano#:~:text=nas%20%C3%A1reas%20consorciadas.-,A%20bovinocultura%20emite%20-menos%20Gases%20de%20Efeito%20Estufa%20(GEEs)%20do,se%20manejados%20com%20t%C3%A9cnicas%20adequadas

European Comission – EC. Joint Research Centre – JRC. Institute for Environment and Sustainability – IES. (2010). *ILCD International Reference Life Cycle Data System. Analysis of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment*. European Union: EC.

Exame. (2019, August 10). Fazenda experimenta vacas com baixa emissão de carbono em prol do planeta. *Exame*. Retrieved from https://exame.com/ciencia/fazenda-experimenta-vacas-com-baixa-emissao-de-carbono-em-prol-do-planeta/

Feeney, E. L., Lamichhane, P., & Sheehan, J. J. (2021). The cheese matrix: Understanding the impact of cheese structure on aspects of cardiovascular health: a food science and a human nutrition perspective. *International Journal of Dairy Technology*, 74(4), 656-670. http://dx.doi.org/10.1111/1471-0307.12755.

Feil, A. A., Schreiber, D., Haetinger, C., Haberkamp, A. M., Kist, J. I., Rempel, C., & Silva, G. R. (2020). Sustainability in the dairy industry: a systematic literature review. *Environmental Science and Pollution Research International*, 27(27), 33527-33542. http://dx.doi.org/10.1007/s11356-020-09316-9. PMid:32566986.

Food and Agriculture Organization of the United Nations – FAO. (2019). *FAO STAT - Livestock Primary*. Roma, Italy.: FAO.

Food and Agriculture Organization of the United Nations – FAO. (2021). *DAIRY market review. Emerging Trends and Outlook*. Retrieved from https://www.fao.org/3/cb7982en/cb7982en.pdf

Gonçalves, N. R. (2017). *Processos químicos na indústria de produção de queijo* (Trabalho de conclusão de curso). Universidade Federal de São João Del-Rei, São João del-Rei. Retrieved from https://ufsj.edu.br/portal-repositorio/File/coqui/TCC/Monografia-TCC-Nayara.pdf

Hajmohammadi, M., Valizadeh, R., Ebdalabadi, M. N., Naserian, A., & Oliveira, C. A. F. (2020). Seasonal variations in some quality parameters of milk produced in Khorasan Razavi Province, Iran. *Food Science and Technology*, 41(Suppl. 2), 718-722. http://dx.doi.org/10.1590/fst.35120.

Lopes, V. C., Guedes, E. K., Candioto, M. V. C., Delvivo, F. M., & Lima, A. R. (2020). Qualidade microbiológica de queijos tipo Minas comercializados em Belo Horizonte, MG, Brasil. *Infarma Ciências Farmacêuticas*, 32(4), 344-352. http://dx.doi.org/10.14450/2318-9312.v32.e4.a2020.pp344-352.

Martins-Costa, T. V. A. (2015). Produção de leite e emissões de metano na região do Corede, RS. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, 67(5), 1381. http://dx.doi.org/10.1590/1678-4162-7785.

Matricarde, V. A. P., Oliveira, I. F., & Factori, M. A. (2021). Reduzir impactos ambientais na produção de ruminantes com uso de aditivos. *Revista Alomorfia*, 5(2), 331-339. Retrieved from https://fatecpp.edu.br/alomorfia/index.php/alomorfia/article/view/109/48

Messias, T. B. O. N., Magnani, M., Pimentel, T. C., Silva, L. M., Alves, J., Gadelha, T. S., Morgano, M. A., Pacheco, M. T. B., Oliveira, M. E. G., & Queiroga, R. C. R. E. (2022). Typical Brazilian cheeses: safety, mineral content and adequacy to the nutritional labeling. *Food Science and Technology*, 42, 1-9. http://dx.doi.org/10.1590/fst.37121.

Milani, F. X., Nutter, D., & Thoma, G. (2011). Environmental impacts of dairy processing and products: a review. *Journal of Dairy Science*, 94(9), 4243-4254.

MilkPoint. (2022, April 26). *Europa: projeto testa aditivo capaz de reduzir gases de efeito estufa*. MilkPoint. Retrieved from https://www.milkpoint.com.br/noticias-e-mercado/giro-noticias/arla-foods-e-dsm-iniciam-projeto-em-grande-escala-para-reduzir-gases-de-efeito-estufa-229826/#:~:text=Europa%3A%20projeto%20testa%20aditivo%20capaz%20de%20reduzir%20gases%20de%20efeito%20estufa,-GIRO%20DE%20NOT%C3%8DCIAS&text=A%20cooperativa%20europeia%20de%20latic%C3%ADnios,leiteiras%20em%20tr%C3%AAs%20pa%C3%ADses%20europeus

Müller, L. J., Kätelhön, A., Bachmann, M., Zimmermann, A., Sternberg, A., & Bardow, A. (2020). A guideline for life cycle assessment of carbon capture and utilization. *Frontiers in Energy Research*, 8(15), 15. http://dx.doi.org/10.3389/fenrg.2020.00015.

Nunes, O. S. (2018). *Análise do ciclo de vida de produtos lácteos: caso de estudo do queijo de Baixa Beira* (Dissertação de mestrado). Universidade da Beira Interior, Covilhã. Retrieved from https://ubibliorum.ubi.pt/bitstream/10400.6/10006/1/6019_12486.pdf

Nunes, O. S., Gaspar, P. D., Nunes, J., Quinteiro, P., Dias, A. C., & Godina, R. (2020). Life-cycle assessment of dairy products: case study of regional cheese produced in Portugal. *Processes*, 1182(8), 1-20. http://dx.doi.org/10.3390/pr8091182.

Palmieri, N., Forleo, M. B., & Salimei, E. (2016). Environmental impacts of dairy cheese chain including whey feeding: an Italian case study. *Journal of Cleaner Production*, 124(186), 1-28.

Rocha, D. T., Carvalho, G. R., & Resende, J. C. (2021). *Cadeia produtiva do leite no Brasil: produção primária* (Circular Técnica, No. 123). Juiz de Fora: Embrapa. Retrieved from https://ainfo.cnptia.embrapa.br/digital/bitstream/item/215880/1/CT-123.pdf

Rodrigues, L. F. S., Pavelquesi, S. L. S., Ferreira, A. C. A. O., Monteiro, E. S., Silva, C. M. S., Silva, I. C. R., & Orsi, D. C. (2022). Microbiological evaluation of industrialized and artisanal Minas fresh cheese commercialized in the Federal District, Brazil. *Food Science and Technology*, 42, e45221.

Rodrigues, W. M. (2021). *Estudos sobre a utilização de óleos essenciais em queijos com alta umidade* (Trabalho de conclusão de curso). Instituto Federal do Espírito Santo, Venda Nova do Imigrante. Retrieved from https://repositorio.ifes.edu.br/bitstream/handle/123456789/1079/TCC_Estudo_%C3%93leos_Queijos_Alta_Umidade.pdf?sequence=1&isAllowed=y

Roque, B. M., Venegas, M., Kinley, R. D., de Nys, R., Duarte, T. L., Yang, X., & Kebreab, E. (2021). Red seaweed (*Asparagopsis taxiformis*) supplementation reduces enteric methane by over 80 percent in beef steers. *PLoS One*, 16(3), e0247820. http://dx.doi.org/10.1371/journal.pone.0247820.

Salum, P., Govce, G., Kendirci, P., Bas, D., & Erbay, Z. (2018). Composição, proteólise, lipólise, perfil de compostos voláteis e características sensoriais de queijos brancos curados fabricados em diferentes regiões geográficas da Turquia. *International Dairy Journal*, 87, 26-36. http://dx.doi.org/10.1016/j.idairyj.2018.07.011.

Siqueira, K., & Schettino, J. P. J. (2021). *O consumo de queijo pelos brasileiros*. MilkPoint. Retrieved from https://www.milkpoint.com.br/colunas/kennya-siqueira/o-consumo-de-queijos-pelos-brasileiros-225212/

Tomich, T. R., Machado, F. S., Pereira, L. G. R., & Campos, M. M. (2015). Nutrição de precisão na pecuária leiteira. *Cadernos Técnicos de Veterinária e Zootecnia*, (79), 54-72.

United Nations Environment Programme – UNEP, Climate and Clean Air Coalition. (2021). *Global methane ssessment: benefits and costs of mitigating methane emissions*. Nairobi: UNEP.

Venturini, K. S., Sarcinelli, M. F., & Silva, L. C. (2007). *Processamento do leite* (Boletim Técnico). Espírito Santo: UFES. Retrieved from http://www.agais.com/telomc/b022_processamento_bovinoleite.pdf

Wang, X., Kristensen, T., Mogensen, L., Knudsen, M. T., & Wang, X. (2016). Greenhouse gas emissions and land use from confinement dairy farms in the Guanzhong plain of China – using a life cycle assessment approach. *Journal of Cleaner Production*, 11, 577-586. https://doi.org/10.1016/j.jclepro.2015.11.099.

Willers, C. D., Rodrigues, L. B., & Silva, C. A. (2013). Avaliação do ciclo no Brasil: uma investigação nas principais bases científicas nacionais. *Production*, 23(2), 436-447. http://dx.doi.org/10.1590/S0103-65132012005000037.

Zhao, R., Xu, Y., Wen, X., Zhang, N., & Cai, J. (2018). Carbon footprint assessment for a local branded pure milk product: a lifecycle based approach. *Food Science and Technology*, 38(1), 98-105. http://dx.doi.org/10.1590/1678-457x.02717.

Zhou, S., Mehta, B. M., & Feeney, E. (2022). A narrative review of vitamin K forms in cheese and their potential role in cardiovascular disease. *International Journal of Dairy Technology*, 75(4), 726-737. http://dx.doi.org/10.1111/1471-0307.12901.

Zocche, L., & Francisco, A. C. (2013). Diagnóstico do Cenário da ACV no Brasil. In *Anais do XXIII Encontro Nacional de Engenharia de Produção*. Salvador.