Journal of Agricultural, Food and Environmental Sciences Vol 78 No 1 (2024) 8-13
DOI:

Original scientific paper

CARBON FOOTPRINT AND EMISSION REDUCTION STRATEGIES IN MILK PROCESSING PLANTS: TOWARDS SUSTAINABLE DAIRY PRODUCTION SYSTEMS

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ABSTRACT

Fluid milk production and processing have a significant impact on greenhouse gas (GHG) emissions, posing risks to global climate stability. This study aimed to quantify the carbon footprint and identify major sources of GHG emissions in three milk processing plants and exploring strategies for emission reduction. The selected plants, referred to as MP1, MP2, and MP3, represented different capacities. Data collection involved visits and surveys at the dairies, gathering information on energy consumption and fuel usage. Emissions were categorized into three scopes: Scope 1 (direct emissions), Scope 2 (indirect emissions from purchased electricity), and Scope 3 (optional emissions beyond the company's control). Direct CO_2e emissions per unit of processed milk were 83.91, 96.12, and 115.71 kg CO_2e /t for MP1, MP2, and MP3, respectively. Emission reduction strategies were proposed, including substituting energy sources with lower GHG potential, replacing refrigerants with lower global warming potentials, improving energy efficiency, and optimizing raw milk procurement and product distribution. It is recommended that milk processing plants establish reduction targets for GHG emissions, focusing on overall emissions and emissions per unit of final product. According to this study, milk processing sectors need to assess and reduce their carbon footprints. Putting emission reduction measures into practice can make dairy production more climate-smart, ensuring the sustainability and effectiveness of milk production.

Key words: Carbon footprint, Emission reduction strategies, Milk processing plants.

INTRODUCTION

The vital task of reducing the release of heat-trapping greenhouse gases (GHGs) into our atmosphere is known as climate change mitigation. Human activities on Earth produce an excess of greenhouse gases, surpassing the capacity of natural carbon and nitrogen cycles to absorb them, and this excess has the potential to modify our climate (Milani et al., 2011). To address this multifaceted dilemma, greenhouse gas emissions from primary sources such as power plants, industry, automobiles, and agricultural operations must be decreased. A comprehensive transformation of our societal behaviors is necessary to efficiently mitigate and avoid these emissions. This transformation has an impact on every aspect of our lives, including how we live, commute, raise food, power our economies, and even make purchasing decisions. Climate change affects communities all across the world locally, making it more than just a worldwide issue (EEA web link, 2023).

The food industry is getting more attention for its impact on climate change, making it increasingly important for it to reduce carbon emissions (Liu et al., 2023). Being a significant contributor to GHG emissions, food industry has a critical responsibility to set climate goals and verify their emissions. In addition to managing their own emissions, it is imperative to consider and incorporate emissions throughout the entire value chain when establishing emission targets (Reavis, 2022).

The dairy industry's future faces the combined task of reducing its environmental footprint while also meeting the expanding demand for animal-based food items. Since nearly 8000 years ago, dairy products have played a significant role in human diets, and they are included in many countries' official nutritional recommendations (Bava et al, 2018).

When the life cycle of dairy products is examined, it becomes clear that dairy processing is the second largest source of greenhouse gas emissions, behind only farm production. Fortunately, technology exists to reduce or eliminate dairy processing's environmental impact. There are numerous successful examples of GHG mitigation and wastewater treatment using alternative technology. Importantly, many of these enhancements have a minor impact on the quality of the dairy materials being processed (Milani et al., 2011). This study aimed to quantify the carbon footprint and identify major sources of GHG emissions in three milk processing plants, exploring strategies for emission reduction.

MATERIALS AND METHODS

In order to investigate ways for reducing emissions, the objective of this research was to evaluate the carbon footprint and identify the main sources of greenhouse gas (GHG) emissions within three milk processing facilities. The manufacturing capacities of the aforementioned plants, designated as MP1, MP2, and MP3, varied.

Data collection encompassed on-site visits and surveys conducted at these dairy facilities. Information was gathered regarding energy consumption, fuel usage, and various pertinent parameters. Specifically, data was collected for daily capacity, annual production figures, types of energy sources used within the dairy processes, annual electricity and fuel consumption, estimates of annual refrigerant use, as well as fuel types and quantities for raw milk purchase and finished product transportation trucks. Based on observed data, our analysis calculates CO_2 emissions at two levels: Scope 1 and Scope 2 emissions. Scope 1 emissions include direct emissions mostly from company-controlled activities such as natural gas combustion, fuel usage in company-owned vehicles, and refrigerants from cooling systems. Indirect emissions (Scope 2) are caused by indirect energy sources, namely electricity supplies and other energy sources used in production.

For the Republic of N. Macedonia, CO_2 emissions data per 1 kWh of electricity produced in 2021 to calculate emissions from purchased electricity were used. This article also provides results for Scope 3 emissions regarding external transport, raw milk, and employees, which were optional for the dairy plants to fill out. The estimation of CO_2e emissions in relation to the type of energy are made according to Defra & DECC (2011) guidelines.

Limitations: This study serves as a preliminary exploration of the carbon footprint and greenhouse gas emissions in milk processing facilities. It does not constitute a full Life Cycle Assessment (LCA), which is the standard method for evaluating the environmental impacts of product systems throughout their entire life cycle. Thus, while the findings offer insights into direct and indirect emissions related to milk processing, they do not account for all upstream and downstream emissions.

RESULTS AND DISCUSSION

Based on the data shown in Table 1, it is evident that diesel fuel is the predominant energy source in all three dairies. Additionally, fuel oil is utilized exclusively in MP1, whilst the utilization of liquid petroleum gas (LPG), butane, and other energy sources is absent. The carbon dioxide equivalent (CO_2e) emissions are primarily correlated with the capacity of the milk facilities.

Among the three plants, the prevalent usage of freon R-404a is seen, which possesses a significant global warming potential of 3920 CO_{2e} (kg). The use of the refrigerant R-410a, often known as freon, is predominantly limited to MP2, and its usage is comparatively reduced due to its significantly higher carbon dioxide (CO_2) emissions, about twice as much as other refrigerants. The impact of refrigerants on global warming potential is a significant concern, as highlighted by (Kosmadakis et al., 2016), who discussed the moderate global warming potential of R-404a and the development of a replacement fluid, R-407f, with similar properties but at a higher cost.

Table 1. Direct emission in three dairy plants

Dairy plant	**MP1**		**MP2**		**MP2**	
	L/kg	kg CO_{2e}	L/kg	kg CO_{2e}	L/kg	kg CO_{2e}
Diesel fuel (L)	24695	61355	51000	126711	464814	1154840
Fuel oil (kg)	161531	486208	/	/	/	/
Refrigerant R-404A (kg)	161531	509600	60	235200	20	78400
Refrigerant R-410A (kg)	130	/	10	20900	/	/
Total	**1057163**		**382811**		**1233240**	

Table 2. CO_2e Emission – Scope 1

CO_2e Emission – Scope 1	**unit**	**MP1**	**MP2**	**MP3**
	[kg CO2e]	1057164	382810	1233240
	[kg CO2e /t]	**83.91**	**96.12**	**115.71**

Based on the data presented in Table 2, MP3 has the highest direct emission of CO_2e per unit of product (0.115 kg CO_2e kg^{-1}), while MP1 has a comparatively lower direct emission. The direct emission of CO_2e per unit of milk processed is influenced by the technical specifications of the equipment used in the milk processing plants. Several studies have reported greenhouse gas (GHG) emissions associated with milk processing, packaging and transport. The study by Nutter et al. (2013) found that GHG emissions for processing were 0.203 kg CO2e kg-1 for all unit operations of packaged milk. The author presented a comparison with other related LCA data in the literature. According to the author, differences in results could be due to products, packaging types/materials, transport vehicle performance and distances, energy emission factors (fuel mix of heating and electricity sources). Gerber et al. (2010) reported that the average GHG emissions from the processing of all products of raw milk are 0.22 kg CO_2e kg^{-1} per kg fat and protein corrected milk (FPCM) at the farm gate. In comparison, in study of Hospido et al, 2003, where are not defined specific unit operations, the reported emissions were 0.183 kg CO2e kg-1 per kg packaged milk. Tan et al. (2011) provided a result of emissions from the processing phase, which was 0.114 kg CO_2e kg^{-1} of packaged milk

Table 3 presents indirect emissions (Scope 2) that come from indirect energy sources, primarily from the supply of electricity and other energy used for the production process.

Table 3. Indirect emissions CO_2 e in dairy plants

	kWh	**Emission CO_2e (kg)**
MP1	839724	293064
MP2	384000	134016
MP3	1693178	590919

The electricity consumption is the highest in MP3, followed by MP1 and the lowest in MP2. The amount of energy consumed depends on the degree of milk processing, that is, the range of products, but also on the technical characteristics of the equipment in the plant. Table 4 presents data indicating that MP3 has the largest CO_2e indirect emission per unit of product, while MP1 has a comparatively smaller direct emission.

Table 4. Indirect emission CO_2e per unit of processed milk

	Unit	**MP1**	**MP2**	**MP3**
CO_2e Emission – Scope 2	[kg CO_2e]	293064	134016	590919
	[kg CO_2e /t]	**23.26**	**33.65**	**55.44**

Tables 5, 6 and 7 show the quantity and type of fuel used on milk facilities. The number of co-operators, their distance from each other and the capacity of the farm all influence the amount of fuel used. It should be noted that 70% of farms in our country have up to 10 cows, which naturally increases fuel prices and therefore emissions. Scope 3 is also affected by the transport choices of employees and the distances they travel to and from customers and stores.

Table 5. Fuel type and quantity for raw milk purchase trucks/tankers

MP1	**L**	**MJ**	**CO_2 e Emissions (kg)**
Diesel fuel	31574	1130349	78446
MP2	**L**	**MJ**	**CO_2 e Emissions (kg)**
Diesel fuel	8400	300720	20870
MP3	**L**	**MJ**	**CO_2 e Emissions (kg)**
Diesel fuel	22751	814486	56525

Table 6. Type of fuel and quantity for the trucks for transporting final products

MP2	**L**	**MJ**	**CO_2e Emissions (kg)**
Diesel fuel	30600	1095480	76026
MP3	**L**	**MJ**	**CO_2e Emissions (kg)**
Diesel fuel	53084	1900407	131888

Table 7. Type of fuel and quantity for employee transport

MP3	**L**	**MJ**	**CO_2e Emissions (kg)**
Diesel fuel	29718	1063904.4	73834.9

In line with the practice of large producers, the surveyed dairies in the dairy industry should set greenhouse gas emission reduction targets based on the reduction of total emissions (e.g. annual CO2 emissions) or on the reduction of emissions per unit of finished product, especially in the area of Scope 1 and Scope 2. As Scope 1 and Scope 2 emissions are the more manageable parts of companies' activities, factories should prioritise minimising these emissions. It is important to consider that some GHG emissions associated with transport could be categorised as Scope 3 emissions. Given the significant GHG emissions associated with the food system, it is essential that the food industry actively works to reduce its GHG emissions. Both GHG verification and GHG mitigation play a critical role in achieving sustainability. The use of standardised methodologies and accurate databases to calculate carbon footprints is crucial for GHG verification (Liu et al, 2023).

Companies should develop short-term (1-3 years) and long-term goals (10 years) in the area of CO_2 emission reduction. The following directions for improvement in the area of CO_2 emission reduction are suggested for the studied dairy plants: Replacing some energy sources with fossil fuels that have a lower GWP (Scope 1); Substitution of refrigerants with lower GWP, especially R-404a whose GWP is 3.920 CO_2/kg; Increasing the energy efficiency of all production lines in order to reduce electricity consumption and optimization of transport during purchase of raw milk and distribution of final products.

CONCLUSION

The study provides an initial assessment of GHG emissions from milk processing plants and suggests several strategies for reduction. It highlights the importance of using energy sources with lower GHG potential, optimising energy efficiency and improving refrigeration practices. However, the results should be considered in the context of this being a preliminary study rather than a full life cycle assessment. Further research should investigate the use of energy efficient technologies, the integration of renewable energy and the development of sustainable practices throughout the life cycle of dairy products. By expanding the scope of environmental assessments to include a full life cycle assessment, dairy producers can more effectively contribute to sustainable production systems and climate change mitigation.

REFERENCES

Bava, L., Bacenetti, J., Gislon, G., Pellegrino, L., D'Inceccoc, P., Sandruccia, A. , Tamburinia, A., Fiala, M., Zucali M. (2018) Impact assessment of traditional food manufacturing: The case of Grana Padano cheese. *Science of The Total Environment* 626:1200–1209. https://doi.org/10.1016/j.scitotenv.2018.01.143

Guidelines to Defra / DECC's GHG (2011) Conversion Factors for Company Reporting: Methodology Paper for Emission Factors

Hospido, A., Moreira, M.T., Feijoo, G., (2003). Simplified life cycle assessment of galician milk production. International Dairy Journal 13, 783–796. https://doi.org/10.1016/S0958-6946(03)00100-6

Kosmadakis, G., Landelle, A., Lazova, M. Manolakos, D., Kaya, A., Huisseune, H., Karavas, C.S., Tauveron, N., Revellin, R., Haberschill, P., Paepe, M.D., Papadakis, G. (2016) Experimental testing of a low-temperature organic Rankine cycle (ORC) engine coupled with concentrating PV/thermal collectors: Laboratory and field tests. Energy 117:222–236. https://doi.org/10.1016/j.energy.2016.10.047

Liu, T.C., Wu, Y.C., Chau, C,F. (2023) An Overview of Carbon Emission Mitigation in the Food Industry: Efforts, Challenges, and Opportunities. *Processes.* 11:1993. https://doi.org/10.3390/pr11071993

Milani, F.X.; Nutter, D.; Thoma, G. (2011) Invited Review: Environmental Impacts of Dairy Processing and Products: A Review. *Journal of Dairy Science*, *94*, 4243–4254, doi:10.3168/jds.2010-3955.
Nutter, D.W., Kim, D.-S., Ulrich, R., Thoma, G., (2013. Greenhouse gas emission analysis for USA fluid milk processing plants: Processing, packaging, and distribution. International Dairy Journal, Carbon and Water Footprint of U.S. Milk, From Farm to Table 31, S57–S64. https://doi.org/10.1016/j.idairyj.2012.09.011
Gerber P., T. Vellinga T., C. Opio C., Henderson B., Steinfeld H. (2010) Greenhouse gas emissions from the dairy sector – A life cycle assessment, Food and Agriculture Organization (FAO) of the United Nations, Animal Production and Health Division, Rome, Italy
Reavis, M., Ahlen, J., Rudek, J., Naithani, K. Evaluating Greenhouse Gas Emissions and Climate Mitigation Goals of the Global Food and Beverage Sector. *Frontiers in Sustainable Food Systems*. 2022;5. https://www.frontiersin.org/articles/10.3389/fsufs.2021.789499
Tan, A., Nutter, D. W., Milani, F. (2011). GHG emissions and energy use from a multi-product dairy processing plant. In Proceedings of the 2011 ASME Early Career Technical Conference (ECTC). American Society of Mechanical Engineers Fayetteville, AR, USA.
https://www.eea.europa.eu/en/topics/in-depth/climate-change-mitigation-reducing-emissions