

Sustainable Dairy Processing: Reducing Carbon Footprint in the Milk Chain

*Navdeep Nain¹ and Sonia Mor²

¹Ph.D. Scholar, Warner College of Dairy Technology, SHUATS, Prayagraj, U.P., India

²Asst. Professor, College of Dairy Science & Technology, RAJUVAS, Bikaner, Rajasthan

*Corresponding Author's email: navdeepnain286@gmail.com

Sustainability is a critical global concern today. As per FAO (2018), a sustainable food system is “a food system that delivers food security and nutrition for all so that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised”. The dairy industry plays a vital role in global food systems, especially in countries like India, where it supports millions of farmers and consumers daily. Yet, behind every glass of milk lies a complex supply chain with a significant environmental footprint. From milk production to processing and packaging, each stage contributes to greenhouse gas (GHG) emissions. In response to growing climate concerns, sustainable dairy processing has emerged as a key strategy to reduce the carbon footprint of dairy operations, without compromising nutrition or livelihoods (Ni *et al.*, 2025).

Carbon Footprint in Dairy Processing

The environmental impact of dairy production spans several interconnected stages, each contributing to greenhouse gas emissions. At the farm level, methane released through enteric fermentation in cattle, along with energy consumption and manure handling, are primary sources of emissions (Sahu *et al.*, 2024). Transporting raw milk to collection centres and processing facilities adds further carbon output due to fuel use. Within dairy plants, operations such as pasteurization, homogenization, chilling, and drying require substantial energy and water resources (Tetra Pak, 2024). Packaging and distribution also play a role, with materials like plastic and the energy demands of refrigeration and logistics increasing the overall footprint. Studies estimate that producing and delivering one litre of milk can result in approximately 1.2 to 2.0 kilograms of CO₂ equivalent emissions. While methane from livestock remains the dominant contributor, the processing and supply chain stages present significant opportunities for emission reduction through sustainable technologies and innovative practices (FAO, 2010).

Key Strategies for Sustainable Dairy Processing

- 1. Energy Efficiency in Processing Plants:** - Dairy processing is energy-intensive, especially during heating and cooling. Upgrading to energy-efficient boilers, motors, and heat exchangers can drastically reduce consumption. Some advanced facilities now use waste heat recovery systems, capturing and reusing thermal energy (Tetra Pak, 2024).
- 2. Renewable Energy Integration:** - Solar panels, biogas digesters, and biomass boilers are increasingly powering dairy plants. Biogas from manure or effluent offers a circular, eco-friendly fuel source, reducing reliance on fossil fuels and lowering methane emissions (Ni *et al.*, 2025).
- 3. Water Conservation and Recycling:** - Water is essential for cleaning and processing. Plants are adopting Zero Liquid Discharge (ZLD) systems to recycle wastewater for non-

critical operations. Clean-in-Place (CIP) systems also minimize water use through automated, efficient cleaning cycles (Sahu *et al.*, 2024).

4. **Eco-Friendly Packaging:** - Plastic waste remains a major concern. Companies are shifting to biodegradable films, glass bottles, and recyclable cartons. Lightweight packaging reduces transportation emissions by lowering fuel consumption (UNEP, 2023).
5. **Cold Chain Optimization:** - Maintaining milk at 4°C from farm to consumer is energy-intensive. Innovations like solar-powered milk chillers and phase change materials (PCMs) help reduce electricity use and spoilage during transport (NDDB, 2022).
6. **Waste Management and Byproduct Utilization:** - Dairy processing generates whey, sludge, and packaging waste. Rather than allowing these outputs to contribute to environmental degradation, many sustainable dairy operations are adopting resource-efficient strategies to repurpose them. Whey, rich in proteins and nutrients, is commonly utilized in the production of nutritional beverages or incorporated into animal feed, enhancing its value within the food system. Sludge, a byproduct of effluent treatment, can be composted and used as organic fertilizer, promoting soil health and reducing reliance on chemical inputs. Packaging waste, particularly plastics and multilayer films, is increasingly being diverted from landfills through recycling initiatives and material recovery programs. These practices not only minimize environmental impact but also support circular economy principles and improve operational sustainability across the dairy value chain.

Policy and Institutional Support for Green Dairy

Public institutions and industry stakeholders are increasingly championing sustainability in the dairy sector. In India, the National Dairy Development Board (NDDB) has taken proactive steps by promoting energy and water audits to help processing units optimize resource use (NDDB, 2022). The Food Safety and Standards Authority of India (FSSAI) complements these efforts through its “Eat Right” initiative, which encourages environmentally responsible food production across the supply chain. Additionally, carbon credit programs are being introduced to reward dairy enterprises that adopt low-emission technologies and practices. These combined efforts are helping to embed sustainability into the operational culture of India’s dairy industry, particularly among small and medium-scale producers.

Rising Consumer Awareness and Market Shifts

Consumer preferences are evolving in response to growing environmental concerns. More individuals are seeking dairy products that reflect sustainable values, such as those labeled “low-carbon milk” or “environment-friendly dairy.” This shift in demand is prompting processors to adopt greener technologies, improve transparency, and communicate their environmental commitments more clearly. As climate-conscious purchasing becomes more mainstream, it is driving meaningful changes throughout the milk supply chain and encouraging companies to align their operations with sustainability goals (UNEP, 2023).

Advantages of Sustainable Dairy Processing in Reducing Carbon Footprint

1. **Reduction in Greenhouse Gas Emissions:** Eco-conscious dairy operations utilize energy-saving machinery and effective waste treatment systems to lower emissions of methane, carbon dioxide, and nitrous oxide. These efforts help shrink the overall environmental impact of milk production and distribution.
2. **Enhanced Energy Efficiency:** By transitioning to renewable energy sources such as solar, wind, and biogas, dairy facilities can significantly reduce their dependence on fossil fuels. Technologies like thermal energy recovery further improve energy utilization, making operations more climate-friendly.
3. **Water Resource Management:** Modern sustainable practices emphasize water conservation through recycling and reduced discharge. Systems like Clean-in-Place (CIP) and Zero Liquid Discharge (ZLD) help optimize water use and minimize waste.

4. Minimization and Repurposing of Waste: Applying circular economy principles allows dairies to transform waste into valuable resources. For example, whey can be used in nutritional products or animal feed, while sludge can be composted, and packaging materials can be recycled—reducing landfill burden.

5. Long-Term Economic Benefits: Although the initial investment in sustainable infrastructure may be substantial, it often results in lower operational costs over time. Savings come from reduced energy consumption, efficient water use, and streamlined waste management.

6. Stronger Brand Image and Consumer Trust: Companies that prioritize environmental responsibility tend to earn greater loyalty from consumers. A commitment to sustainability can enhance brand reputation and open doors to environmentally conscious markets.

7. Compliance with Environmental Regulations: As climate-related policies become more stringent, adopting sustainable methods helps dairy businesses stay compliant, avoid penalties, and mitigate operational risks.

8. Contribution to Climate Action Goals: Green dairy practices support broader climate initiatives, including national commitments and international frameworks like the Paris Agreement and the UN Sustainable Development Goals (SDGs).

9. Protection of Natural Ecosystems: Reducing pollution and conserving natural resources helps safeguard soil health, air quality, and water systems. This, in turn, supports biodiversity and ecological resilience.

10. Catalyst for Innovation: The push for sustainability encourages research and the development of new technologies. This drive for innovation leads to cleaner, more efficient dairy processing methods and fosters continuous improvement across the industry.

Conclusion

Sustainable dairy processing is no longer optional; it's essential. Through smart technologies, renewable energy, efficient resource use, and responsible waste management, the dairy sector can significantly reduce its carbon footprint. This transformation not only benefits the planet but also strengthens consumer trust, regulatory compliance, and long-term profitability. The future of dairy lies in balancing tradition with innovation, nutrition with responsibility, and livelihoods with environmental stewardship.

References

1. Food and Agriculture Organization. (2018). Sustainable food systems: Concept and framework. FAO.
2. Food and Agriculture Organization. (2010). *Greenhouse gas emissions from the dairy sector: A life cycle assessment*. FAO.
3. National Dairy Development Board. (2022). *Sustainable dairy initiatives and energy audits*. NDDDB Reports.
4. Ni, H., Zeng, H., Liu, Z., Li, W., Miao, S., Yang, A., & Wang, Y. (2025). Towards decarbonizing the supply chain of dairy industry: Current practice and emerging strategies. *Carbon Neutrality*, 4, Article 8.
5. Sahu, R., Tripathi, A.K., Shukla, N., & Paikra, C.K. (2024). Examining the carbon emissions from dairy supply chains: An in-depth review. *International Journal of Advanced Biochemistry Research*, SP-8(4), 540–546.
6. Tetra Pak. (2024). *Sustainability in dairy processing*. In *Dairy Processing Handbook*.
7. United Nations Environment Programme. (2023). *Sustainable packaging and consumer behaviour in food systems*. UNEP Publications.