SUSTAINABLE DAIRY FOR A BETTER TOMORROW: NOURISHING PEOPLE, PRESERVING THE PLANET

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ABSTRACT

India's dairy sector, the largest globally, supports over 70 million rural households with essential nutrition and livelihoods. However, it faces major sustainability challenges, including methane emissions, high water use, and manure management. This article examines how India is tackling these issues through grassroots innovations and climate-smart technologies - ranging from low-emission feeding, biogas systems, and solar chilling to AI-driven logistics. Led by cooperatives like Banas Dairy and NDDB, the sector is evolving, but obstacles like high costs, low awareness, and policy gaps hinder progress. The article calls for farmer training, financial incentives, and a supportive investment ecosystem to scale green practices. By showcasing community-led models, it presents green dairy not only as an environmental necessity but as a pathway to sustainable nourishment for people and planet.

KEYWORDS: Sustainable Dairy, Climate-Smart Agriculture, Methane Emissions, Livelihoods and Nutrition, Biogas and Renewable Energy, Indian Dairy Sector, NDDB

INTRODUCTION

Your daily glass of milk may seem routine, but it represents a complex nexus of land use, water resources, animal welfare, and livelihoods. In India, dairy is more than food - it's an economic lifeline for over 70 million rural households and a driver of national development. As the world's largest milk producer, India contributes nearly 24% of global output, with production projected to reach 242 million tonnes in 2023–24. This growth is powered by scientific interventions and one of the world's largest dairy cooperative networks, shaped by Operation Flood. The sector contributes 5.2% to national GDP and over 66% of the livestock sector's output, making it central to rural economic stability (NDDB, 2023; Gaillard & Dervillé, 2022; Sarkar *et al.,* 2024).

Yet, this success comes at an environmental and ethical cost. Dairy is India's largest source of methane emissions, driven by enteric fermentation and manure management, positioning it as a key area for climate mitigation (MoEFCC, 2021). It is also water-intensive, largely due to fodder cultivation, increasing pressure on scarce freshwater reserves (FAO, 2017). Moreover, animal welfare challenges - such as tethering, heat stress, and poor hygiene - persist in many dairy systems, impacting both health and productivity (Mullan *et al.,* 2020). This article explores how India can retain dairy's nutritional and economic benefits while addressing these concerns through climate-smart technologies, biogas systems, and sustainable innovations that align dairy production with environmental responsibility and ethical care.

The Sustainability Challenge in Dairy

Dairy plays a dual role in India - as a vital source of rural nutrition and a key income stream for millions. Yet, the sector is facing rising environmental scrutiny. The challenge lies in producing milk that nourishes millions without worsening climate change, exhausting water resources, or damaging ecosystems.

A primary concern is greenhouse gas (GHG) emissions, especially methane from enteric fermentation in ruminants. Livestock contributes

14.5% of global GHGs, with dairy cattle alone accounting for over 20% (Gerber *et al.,* 2013). In India, the problem is even more critical: in 2016, livestock was responsible for 54.6% of national methane emissions, largely from smallholder systems using inefficient feeding and manure practices (MoEFCC, 2021). Compounding this is dairy's high-water footprint - producing one litre of milk uses 1,000–1,200 litres of water, mainly for fodder cultivation (Mekonnen & Hoekstra, 2012). In water-stressed areas, this intensifies conflicts over resource use. Manure mismanagement adds further strain, emitting methane and nitrous oxide, and contributing to pathogen spread, odor pollution, and water contamination (Symeon *et al.,* 2025).

Despite these pressures, dairy remains nutritionally indispensable - providing affordable protein, calcium, and micronutrients, especially to low-income families, children, and women-led households (Dominic *et al.,* 2022). The core dilemma is clear: how to balance dairy's food security role with its environmental cost. The answer lies in adopting sustainability innovations - from smarter feeding to improved waste systems - enabling India to lead a shift toward climate-smart dairy systems that benefit both people and the planet.

GREEN INNOVATIONS: FROM FARM TO DAIRY PLANT

Sustainability in Indian dairy is no longer aspirational - it is a visible transformation across the entire value chain, from livestock feeding to milk processing. A combination of technological and ecological innovations is steadily reducing the sector's environmental footprint and creating scalable, climate-resilient models.

3.1. Low-Emission Livestock Management

Methane emissions from ruminant digestion remain a major concern. Feed additives like 3-nitrooxypropanol (3-NOP) inhibit microbial enzymes responsible for methane formation (Neethirajan, 2024), while tannin-based diets and probiotics enhance digestion and reduce emissions. The NDDB's Ration Balancing Programme (RBP) supported over 28,000 farmers across 480 villages in 2023-24, delivering tailored feeding strategies through trained advisors - improving both yields and feed efficiency (NDDB, 2023). Cross-breeding programs further reduce emissions per litre by combining high-yield traits with local breed resilience.

3.2. Manure and Waste Management

Manure, often an environmental liability, is now a renewable energy source. Anaerobic digesters transform animal waste into biogas, accounting for over 50% of voluntary carbon credits globally (Thornton *et al.,* 2024). NDDB has shown that balanced rations can reduce the carbon footprint of milk by up to 30%, while composting and anaerobic digestion improve nutrient recycling and reduce methane and nitrous oxide emissions (Neethirajan, 2024).

3.3. Renewable Energy Adoption

Dairy cooperatives are cutting Scope 2 emissions with solar thermal systems and biogas energy. For example, Himachal Milkfed saves 14,000 litres of diesel annually by using solar-heated water. In Maharashtra, dairies like Mahanand and Dudhmansagar have adopted solar-based chilling and pasteurization, reducing fossil fuel dependence (Patel *et al.,* 2016). Off-grid solar-powered chillers and biogas cooking systems are especially impactful in remote villages (Neethirajan, 2023).

3.4. Water-Smart Dairy Practices

Water-saving technologies are reshaping processing operations. CIP (Clean-in-Place) systems consume up to 28% of plant water, prompting reuse via ultrafiltration and reverse osmosis (Meneses & Flores, 2016). At the farm level, rainwater harvesting, real-time water metering, and training programs are helping farmers reduce borewell reliance and use water more efficiently for livestock and fodder.

3.5. *AI and IoT in Sustainability*

AI and IoT are ushering in digital transformation across the sector. Firms like Hatsun Agro have reduced spoilage by over 25% using AI-based inventory systems. Smart feeding and milking tools, powered by real-time animal data, optimize feed and detect early signs of illness. In cold chains, IoT sensors monitor temperature, humidity, and pH, feeding data into AI systems that can issue spoilage alerts 2–4 hours in advance, boosting both safety and supply chain efficiency (Prajapati *et al.,* 2025).

Together, these interventions in feed, energy, water, waste, and digital infrastructure are reshaping Indian dairying. With supportive policies and strategic scaling, they can form the

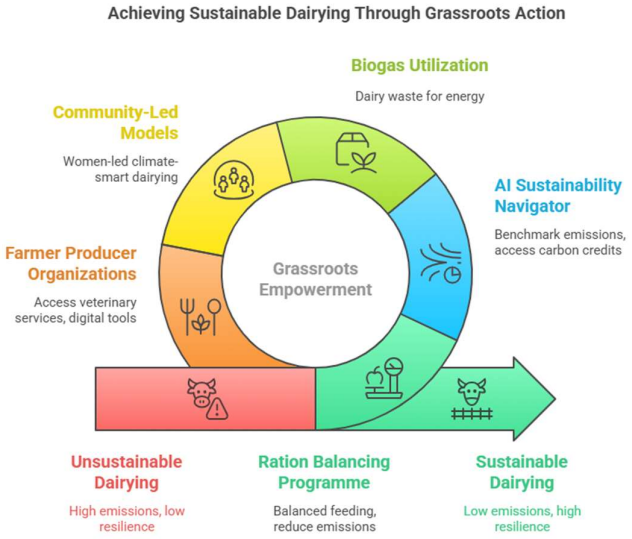
backbone of a climate-smart, economically viable dairy ecosystem.

INDIA'S ROLE: LEADING BY GRASSROOTS ACTION

India's shift to sustainable dairying is fueled not only by policy but by a robust grassroots ecosystem of cooperatives, SHGs, and community-led initiatives. Central to this transformation is the NDDB's Ration Balancing Programme, expanded through A-HELP, which trains Pashu Sakhis to deliver climate-smart feeding advice - improving animal health, productivity, and GHG reduction (NDDB, 2023). Tools like the Sustainability Navigator use AI to track emissions and link performance to carbon credits and green finance (Neethirajan, 2023).

Grassroots innovations also promote renewable energy, with biogas systems now used for heating, power, and milk chilling, especially in off-grid areas - though high capital costs remain a barrier (Patel *et al.,* 2016). In low-income, climate-sensitive regions, women-led models are advancing climate-smart dairying through biogas, organic inputs, and resilient livestock practices, promoting both sustainability and gender equity (Thornton *et al.,* 2024). Meanwhile, FPOs enhance access to markets, veterinary services, and digital advisory tools, enabling wider adoption of sustainable practices.

These community-driven efforts position India as a global leader in inclusive, climate-smart dairy, rooted in local resilience and technological empowerment.



CHALLENGES AND THE ROAD AHEAD

India's progress toward sustainable dairying is promising but faces several critical barriers that threaten to slow momentum. One major obstacle is the high upfront cost of technologies like biogas systems. While they offer long-term benefits - such as GHG reductions and production of digestate (an organic fertilizer) - they remain unaffordable for many small-scale farmers without access to credit, subsidies, or green financing (Mignogna *et al.,* 2023).

A second challenge is limited technical awareness. Many farmers are unfamiliar with climate-smart feeding, AI tools, or emission-tracking systems. As the NDDB highlights, technology alone is not enough; widespread adoption depends on capacity-building, training, and peer-led support systems (NDDB, 2023).

Policy fragmentation adds further complexity. Weak incentives, inconsistent regulations, and a lack of alignment across government programs hinder the system-wide adoption of sustainable practices. Moreover, India's nascent carbon market lacks standardized metrics for evaluating environmental performance, restricting farmers' access to carbon finance and green rewards (Neethirajan, 2023).

To address these gaps, three strategic actions are essential:

- **Training and Extension:** Scale farmer education through SHGs, FPOs, and mobile advisory platforms to improve adoption of sustainability innovations.

- **Financial Incentives:** Offer green loans, carbon credits, and tax benefits to reduce adoption risks and support investment.
- **Ecosystem Collaboration:** Promote public-private partnerships and align policies to co-develop scalable, inclusive solutions tailored to smallholder systems.

With these enablers, India's dairy sector can emerge as a global model for climate-smart, farmer-centric innovation, transforming environmental challenges into rural prosperity and food security.

CONCLUSION

Dairy will remain a vital pillar of nutrition and rural livelihoods in India, playing a crucial role in child and maternal health while sustaining millions of smallholder households. However, to stay viable in a climate-constrained future, the sector must embrace climate-smart, grassroots-led innovations such as low-emission feed additives, solar-powered chilling systems, and AI-integrated supply chains - many already being adopted by women-led cooperatives and community-based organizations. India is uniquely positioned to lead the global transition to sustainable dairy production, not just through technology, but through people-powered approaches rooted in traditional knowledge and local resilience. Still, key barriers remain, including high upfront costs, limited technical awareness, and fragmented policy structures. With the right blend of targeted investments, farmer training, and coordinated policy frameworks, India's dairy sector can deliver sustainable nourishment at scale without environmental compromise. Green dairy is not a choice but a necessity - a path toward a cooler, kinder, and climate-ready future for both people and the planet.

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