

Dairy and Plant-Based Milks: Environmental, Nutritional and Market Trade-offs for Indian Agribusiness

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ABSTRACT

Plant-based milks are widely promoted as low-impact alternatives to cow's milk, but their environmental, nutritional and market trade-offs are seldom assessed together, and evidence for India, the world's largest milk producer, is fragmented. This structured narrative review synthesises 34 sources selected under explicit eligibility criteria and an evidence hierarchy that reserves environmental and nutritional claims for peer-reviewed and official sources and uses industry and non-governmental reports only to describe markets and consumers. Global life cycle assessment (LCA) evidence indicates that, per litre, cow's milk generates about 3.2 kg CO₂-equivalent, 628 litres of freshwater withdrawals and 9 m² of land occupation, compared with roughly 0.7–1.0 kg CO₂e and 0.5–0.8 m² for soy, oat and almond beverages. Soy and oat beverages require 13–22 times less freshwater withdrawal than dairy, whereas almond beverages require about 40 per cent less; water results depend strongly on whether withdrawals, consumption, scarcity-weighted use or the total green–blue–grey water footprint is reported. The advantage narrows on a nutrient basis: most plant beverages are low in protein and iodine unless fortified, and fortified soy beverages are generally the closest nutritional match to milk. India-specific evidence is limited to national emission inventories, livestock methane estimates and industry market surveys; no Indian LCA directly comparing dairy and plant-based milks was identified. Indian plant-based dairy was valued at about ₹210 crore in FY 2024, and small online surveys (n = 220 and 288) indicate that most users continue to consume dairy, with price and taste as key barriers. The review proposes a two-track agribusiness pathway, reducing the emission and water intensity of dairy while developing farmer-linked soybean and millet beverage chains, and identifies priority research gaps, notably India-specific LCAs of cow, buffalo and millet-based milks.

Keywords: *Life cycle assessment; Dairy milk; Plant-based milk; Environmental footprint; Nutrient density; Indian agribusiness*

1. Introduction

Milk occupies a central place in Indian diets, culture and rural livelihoods. India is the world's largest milk producer, with an estimated output of 239.3 million tonnes in 2023–24, and Rajasthan is the second-largest producing state, contributing 14.5 per cent of national production (DAHD, 2024). At the same time, dairy production is under growing environmental scrutiny because of its greenhouse gas (GHG) emissions, water use and land demand (FAO, 2010; Gerber et al., 2013). Plant-based beverages made from soy, oats, almonds and, more recently, millets are increasingly marketed as lower-impact alternatives. Global life cycle assessment (LCA) studies broadly support this claim on a per-litre basis (Berardy et al., 2022; Poore & Nemecek, 2018; Ramsing et al., 2023). The market has grown accordingly: global retail sales of plant-based milk were estimated at US\$18.7 billion in 2023 (Good Food Institute [GFI], 2024), and plant-based dairy now accounts for most of India's small plant-based foods market (Ipsos & Plant Based Foods Industry Association [PBFIA], 2025).

Four key gaps constrain the applicability of the existing evidence for Indian decision-makers. First, environmental, nutritional, and market dimensions are typically examined independently, despite their substantial interrelationships. Second, the majority of life-cycle assessment (LCA) studies originate from Europe and North America and predominantly focus on cow's milk, whereas a significant proportion of India's milk production is derived from buffaloes within smallholder production systems. Third, environmental indicators, particularly those related to water use, are reported inconsistently across studies, resulting in direct comparisons of metrics that may represent fundamentally different measures. Fourth, relatively few studies translate the available evidence into actionable options and implications for Indian farmers, processors, and policymakers. This review addresses four research questions: (RQ1) How do the GHG, water and land footprints of cow's milk compare with those of soy, oat, almond and millet-based beverages in the global LCA literature? (RQ2) How do nutritional composition, fortification and price qualify these comparisons? (RQ3) What India-specific evidence exists on dairy emissions, water stress, and the plant-based milk market and its consumers? (RQ4) What are the implications for Indian agribusiness, and where are the main evidence gaps? The review makes three contributions. It integrates environmental, nutritional and market evidence within a single conceptual framework (Figure 1); it explicitly separates global LCA evidence from India-specific evidence and grades the confidence of each key finding; and it translates the findings into stakeholder-specific agribusiness implications and a research agenda suited to Indian agricultural universities and research institutions.

2. Methodology

2.1 Review design

A structured narrative review was conducted. A systematic review with meta-analysis was not attempted because the evidence is methodologically heterogeneous: LCAs differ in functional unit, system boundary and impact metric; nutrient studies rely on label data from different markets; and market evidence consists of industry estimates. Pooling such data statistically would be inappropriate. To improve transparency and reproducibility, the review nevertheless followed defined procedures for searching, eligibility, evidence grading, data extraction and confidence assessment, described below.

2.2 Search strategy

Peer-reviewed literature was identified through systematic keyword searches of Google Scholar, PubMed Central, and major publisher platforms, including ScienceDirect, SpringerLink, MDPI, and the ICAR e-publishing platform. These searches were supplemented by backward citation tracking of key review articles (Berardy et al., 2022; Ramsing et al., 2023). Official documents were obtained directly from the websites of the Food and Agriculture Organization (FAO), Intergovernmental Panel on Climate Change (IPCC), United Nations Framework Convention on Climate Change (UNFCCC), and relevant Government of India ministries and authorities. Industry and non-governmental organisation reports concerning plant-based milk were identified through organisational websites and reports compiled by the authors. The final literature searches were completed in October 2026. The search terms employed are summarised in Table 1.

Table 1: Search strategy

Evidence domain	Main search terms (combined with AND / OR)	Sources searched
Environmental footprints	“plant-based milk”, “plant-based beverage”, “soy drink”, “oat drink”, “almond milk”, “dairy milk” AND “life cycle assessment”, “carbon footprint”, “water footprint”, “land use”	Google Scholar, PubMed Central, ScienceDirect, SpringerLink
Indian dairy emissions and water	“India” AND “dairy” OR “livestock” AND “methane”, “greenhouse gas”, “enteric fermentation”, “groundwater”	Google Scholar, ICAR e-publishing, UNFCCC, MoEFCC, DAHD
Nutrition and fortification	“plant-based milk” OR “milk alternative” AND “nutrient”, “protein”, “iodine”, “fortification”, “nutrient density”	PubMed Central, MDPI, Cambridge Core
Market, consumers and regulation	“plant-based dairy” OR “plant-based milk” AND “India” AND “market”, “consumer”, “survey”, “regulation”	GFI, GFI India, Ipsos, PBFIA, FSSAI, ProVeg, WWF-UK, Healthy Eating Research

Note: Publications published between 2009 and 2025 were considered for the primary evidence base, while methodological standards were included irrespective of their publication date. The final literature search was completed in October 2026.

2.3 Eligibility criteria

Sources were eligible for inclusion if they met one or more of the following criteria: (a) peer-reviewed life-cycle assessments (LCAs), meta-analyses, or review studies reporting greenhouse gas (GHG) emissions, water use, or land use per unit of dairy or plant-based milk; (b) peer-reviewed studies examining the nutrient composition of plant-based milks or nutrient-adjusted climate-impact metrics; (c) official inventories, statistical datasets, legislation, or policy documents relevant to India; or (d) industry, academic, or non-governmental reports addressing plant-based milk markets, consumer behaviour, or product composition, provided that their data sources were disclosed and, where surveys were conducted, the sample was reported. Only English-language documents were considered. News articles, blogs, company marketing materials, paywalled market-forecast summaries lacking transparent methodological information, and studies focused exclusively on plant-based meat were excluded.

2.4 Evidence hierarchy

A total of 34 sources were retained and classified into four evidence tiers (Table 2). The environmental and nutritional claims presented in this review are primarily supported by Tier A and Tier B sources. Tier C sources were used exclusively to characterise market size, retail prices, consumer behaviour, and product-label audits, and are explicitly identified as such wherever cited. Potential conflicts of interest were also considered. GFI, GFI India, and ProVeg International have an organisational focus on promoting alternative proteins, while PBFIA represents the plant-based food industry. In addition, three authors of one nutrient-density study received funding from a national dairy council (Scarborough & Rayner, 2010).

Table 2: Evidence hierarchy used to classify and assess sources included in the review.

Tier	Type of source	n	Permitted use within the review
A	Peer-reviewed journal articles (LCAs, meta-analyses, reviews, nutrient and emission studies)	15	Environmental, nutritional and emission claims
A-M	Methodological standards and manuals (ISO 14046; Water Footprint Assessment Manual)	2	Definitions of metrics
B	Official and intergovernmental sources (IPCC, FAO, UNFCCC submissions, DAHD, FSSAI)	9	Inventories, statistics, regulation and policy
C	Industry, academic-programme and non-governmental reports and data portals (GFI, GFI India, Ipsos–PBFIA, ProVeg, WWF-UK, Healthy Eating Research, Our World in Data)	8	Market size, prices, consumer surveys and label audits only; always identified

Note: Our World in Data (Ritchie, 2022) is used solely as a presentation and visualisation of the peer-reviewed dataset reported by Poore and Nemecek (2018).

2.5 Data extraction and harmonisation

For each source, the following information was extracted: geographical context, reference year, product type, functional unit, system boundary, impact metric, sample size (for surveys and product audits), and funding or institutional affiliation. Environmental comparisons were harmonised to a common functional unit of one litre of product at the retail stage, using the global mean estimates reported by Poore and Nemecek (2018), as presented by Ritchie (2022). This dataset was selected because it was the only included source reporting all four milk categories using a common methodological framework. Percentage differences between products were calculated by the authors based on these values. No statistical pooling or meta-analytic aggregation was undertaken; instead, estimates from individual product-level studies are reported alongside the harmonised values to capture the observed variability. Market values are presented in the currency and reference year reported in the original source and were not adjusted for inflation.

2.6 Appraisal and confidence rating

Each key finding was assigned a confidence rating. High confidence was assigned where a finding is consistent across at least two independent Tier A or Tier B sources; moderate confidence where it rests on a single Tier A source or on consistent Tier C sources with stated methods; and low confidence where it rests on a single industry estimate, a small non-probability sample, or a projection. The ratings are summarised in Table 9.

2.7 Conceptual framework

Figure 1 presents the conceptual framework underpinning the review. Product alternatives are assessed across three dimensions: environmental performance, nutritional characteristics, and economic or market performance. The translation of these dimensions into agribusiness implications is contextualised by Indian conditions, including groundwater stress, buffalo-based smallholder dairy systems, the country's soybean and millet production base, food regulatory frameworks, and climate policy. The evidence gaps identified through the review further inform the proposed research agenda.

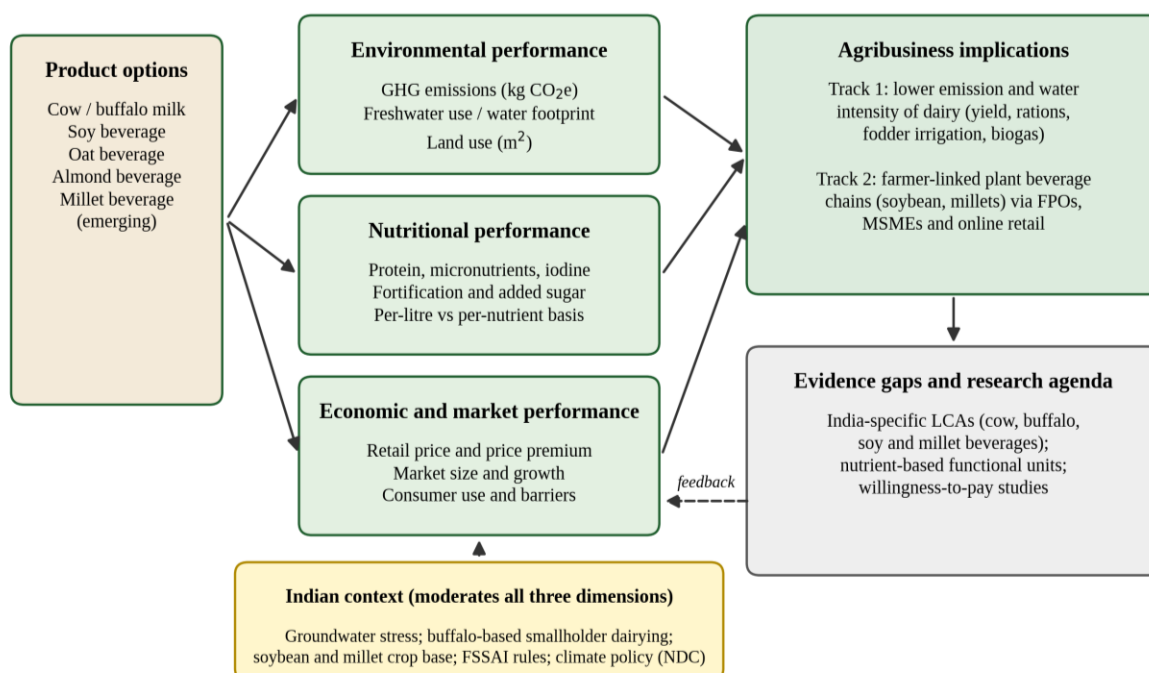


Figure 1: Conceptual framework of the review. Source: Developed by the authors.

3. Environmental Impact Metrics and Measurement Framework

Published milk footprints are frequently compared despite measuring different quantities. Table 3 defines the metrics used in this review. The distinction is particularly important for water. Freshwater withdrawals measure irrigation and process water extracted from surface or groundwater; freshwater consumption measures the share of this water not returned to its source; scarcity-weighted use adjusts consumption for local water availability (Boulay et al., 2018); and the total water footprint combines blue water with rainfall used by crops and pastures (green water) and water required to dilute pollutants (grey water) (Hoekstra et al., 2011). As these quantities can differ several-fold for the same product, this review compares products only within the same metric.

Table 3: Environmental impact metrics adopted for assessment, including their definitions, measurement basis, and interpretation.

Metric (unit)	What it measures	Primary Evidence Source(s)	Interpretation note
GHG emissions (kg CO₂e per litre)	CO ₂ , CH ₄ and N ₂ O from land use change, farming, processing, packaging and transport to retail, weighted by 100-year global warming potential (GWP100)	Poore & Nemecek (2018); FAO (2010)	Biogenic CH ₄ GWP100 is about 27 in IPCC (2021); older studies use other values, and boundaries differ between studies
Freshwater withdrawals (L per litre)	Blue water taken from rivers, canals or aquifers for irrigation and processing	Poore & Nemecek (2018)	Excludes rainfall; does not show whether water is returned
Freshwater consumption (L per litre)	Withdrawn water that is evaporated, incorporated or not returned	Winans et al. (2020)	Usually lower than withdrawals for the same product
Scarcity-weighted water use	Consumption multiplied by a local water-scarcity factor (e.g., AWARE)	Boulay et al. (2018)	Captures where water is used; most relevant for arid regions
Total water footprint (L per kg)	Green (rainfall) + blue (surface and groundwater) + grey (pollution dilution) water	Hoekstra et al. (2011); Mekonnen & Hoekstra (2012)	Not comparable with withdrawals; dominated by green water for animal products
Land use (m² per litre)	Annual land occupation for crops, pasture and facilities	Poore & Nemecek (2018)	Does not capture land quality or biodiversity value

Source: Compiled by the authors; water footprint concepts follow ISO (2014) and Hoekstra et al. (2011).

4. Global LCA Evidence on Environmental Footprints

4.1 Cow's milk

Methane (CH₄) from enteric fermentation and manure is the largest source of dairy emissions, accounting for about 52 per cent of the sector's GHG emissions, with nitrous oxide from feed production and manure and carbon dioxide from energy use making up the remainder (FAO, 2010). FAO estimated that the dairy sector, including meat from dairy herds, accounted for about 4 per cent of global anthropogenic GHG emissions, or 2.7 per cent for milk alone, with a global average of about 2.4 kg CO₂e per kg of fat-and-protein-corrected milk (FAO, 2010). This figure is lower than the 3.2 kg CO₂e per litre reported by Poore and Nemecek (2018) because the two studies differ in functional unit, system boundary and reference year, which illustrates why published dairy footprints vary.

Emission intensity varies widely between production systems. Per kilogram of milk, emissions are highest in sub-Saharan Africa and South Asia and lowest in North America and Europe, mainly because low-yielding animals spend a larger share of their feed energy on body maintenance (FAO, 2010; Gerber et al., 2013). Wider adoption of existing best practices in feeding, animal health, breeding and manure management could reduce livestock emissions by up to about 30 per cent (Gerber et al., 2013). These measures reduce, but are unlikely to eliminate, enteric methane.

4.2 Plant-based beverages

Most LCA data on plant-based milks concern soy and almond beverages, and GHG emissions are the most commonly reported impact (Berardy et al., 2022). On a per-litre basis, soy beverages generate about 1.0 kg CO₂e, 28 litres of freshwater withdrawals and 0.7 m² of land use (Poore & Nemecek, 2018). An Italian supply-chain study confirmed a lower carbon

footprint for soy drink than for cow's milk, but found that about 13 per cent more soy drink was needed to supply the protein in a litre of milk (Coluccia et al., 2022). Oat beverages have similar carbon (0.9 kg CO₂e) and land (0.8 m²) footprints and require about 48 litres of freshwater withdrawals per litre, although fewer product-level LCAs are available (Berardy et al., 2022; Poore & Nemecek, 2018). Almond beverages have the lowest carbon (0.7 kg CO₂e) and land (0.5 m²) footprints of the three but require about 371 litres of freshwater withdrawals per litre because almond orchards are irrigated (Poore & Nemecek, 2018). Product-level results can differ substantially from these means: an LCA of one Californian unsweetened almond beverage reported 0.71 kg CO₂e and 175 kg of freshwater consumption per 1.42-litre bottle, equivalent to roughly 0.5 kg CO₂e and 123 litres per litre (Winans et al., 2020).

Millet-based beverages are an emerging Indian product category, and industry sources report rapid scale-up by some manufacturers (Ipsos & PBFIA, 2025). Millets are hardy and largely rain-fed, which suggests potential for a low water footprint. However, no peer-reviewed LCA of a millet-based beverage was identified in this review, so their environmental performance remains to be established. Table 4 and Figure 2 summarise the global footprints.

Table 4: Environmental footprints and protein content of cow's milk and plant-based beverages (per litre)

Type of milk	GHG emissions (kg CO ₂ e/L)	Freshwater withdrawals (L/L)	Land use (m ² /L)	Protein (g/100 ml)*	Key trade-off
Cow milk	3.2	628	9.0	3.3	High nutrient density; methane-intensive and feed-water demanding
Soy beverage	1.0	28	0.7	2.9	Protein close to dairy; nitrogen-fixing crop; allergen and flavour concerns
Oat beverage	0.9	48	0.8	0.8	Low water withdrawal; low protein unless fortified; fewer LCAs
Almond beverage	0.7	371	0.5	0.4	Lowest carbon and land use; high irrigation demand
Millet beverage	n.a.	n.a.	n.a.	n.a.	Rain-fed crop base; no peer-reviewed LCA identified

Source: Environmental footprints represent global mean estimates from Poore and Nemecek (2018), as presented by Ritchie (2022). *Protein values refer to specific unsweetened products marketed in the USA and were converted from per-serving data reported by Healthy Eating Research (2025); values may vary by brand. n.a. = not available.

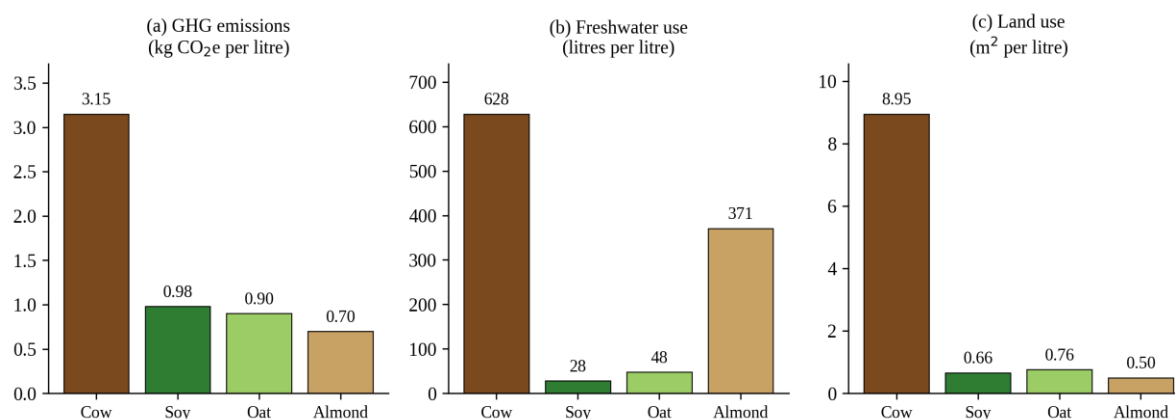


Figure 2: Per-litre (a) GHG emissions, (b) freshwater withdrawals and (c) land use of cow's milk and three plant-based beverages. Source: Poore & Nemecek (2018); Ritchie (2022).

4.3 Water Use and the influence of measurement metrics

Measured as freshwater withdrawals, soy and oat beverages require roughly 13 to 22 times less water than cow's milk, whereas almond beverages require about 40 per cent less (calculated from Poore & Nemecek, 2018). The total water footprint of milk, which includes green and grey water, is considerably larger, at a global average of about 1,020 litres per kilogram, and for animal production as a whole roughly 87 per cent of the water footprint is green water from rainfall (Mekonnen & Hoekstra, 2012). The figures of 628 litres and about 1,000 litres are therefore not contradictory; they measure different quantities. Location also matters: a litre of water withdrawn from a depleted aquifer has a greater impact than a litre drawn from an abundant source, which is why scarcity-weighted methods have been developed (Boulay et al., 2018). Rain-fed crops such as soybean and millets are therefore likely to compare more favourably on scarcity-weighted metrics than irrigated almonds, although this has not yet been quantified for Indian production.

4.4 Greenhouse gas emissions and their drivers

Per litre, replacing cow's milk with a soy beverage reduces GHG emissions by about 69 per cent, with an oat beverage by about 71 per cent and with an almond beverage by about 78 per cent (calculated from Poore & Nemecek, 2018). The difference arises mainly because plant beverages involve no enteric methane; their emissions come from crop cultivation, processing energy, packaging and transport (Berardy et al., 2022; Winans et al., 2020). Global means conceal wide variation between producers; nevertheless, Poore and Nemecek (2018) found that the impacts of the lowest-impact animal products typically exceed those of their plant-based substitutes. Table 5 summarises the main drivers.

Table 5: Main drivers of the carbon and water footprints of different milks

Type of milk	Main GHG sources	Enteric methane	Main water demand
Cow milk	Enteric fermentation, manure management, feed and fodder production, processing and cooling	Yes (dominant)	Irrigated fodder and feed crops; rainfall on pasture and crops
Soy beverage	Crop cultivation, processing energy, packaging, transport	No	Largely rain-fed crop; processing water
Oat beverage	Fertiliser use in cultivation, processing energy, packaging	No	Largely rain-fed crop; processing water
Almond beverage	Orchard operations, processing energy, packaging	No	Irrigated orchards

Source: Compiled by the authors from FAO (2010), Berardy et al. (2022), Ramsing et al. (2023) and Winans et al. (2020).

5. India-Specific Evidence

This section presents India-specific evidence separately from the global evidence base because the structure and characteristics of the Indian dairy system differ from those represented in most life-cycle assessments (LCAs). No India-specific LCA directly comparing dairy milk with plant-based beverages was identified.

5.1 Emissions from Indian dairying

According to India's Third Biennial Update Report, agriculture contributed about 14 per cent of national GHG emissions in 2016, and enteric fermentation in livestock was the largest source within agriculture, at about 55 per cent of agricultural emissions (MoEFCC, 2021). India had about 302 million cattle and buffaloes at the 20th Livestock Census (DAHD, 2019). Dixit and Birtal (2016) estimated total methane emissions from Indian livestock at 12.28 million tonnes for the 2012 livestock population and found that buffaloes contributed about 40 per cent of enteric methane from bovines while accounting for 36 per cent of the bovine population. In a study of the food production underlying Indian diets, rice and ruminant products had the highest GHG emissions among food groups (Vetter et al., 2017). Because a large share of Indian milk comes from buffaloes, global LCA values for cow's milk may not represent Indian conditions, and the emission intensity of Indian milk per litre remains poorly characterised.

5.2 Water stress and regional context

Satellite-based measurements showed substantial groundwater depletion across Rajasthan, Punjab and Haryana between 2002 and 2008, attributed mainly to irrigation (Rodell et al., 2009). In this setting, irrigated green fodder for dairy animals competes with food crops for groundwater, while rain-fed crops such as pearl millet in western Rajasthan and soybean in the state's south-eastern districts draw less on aquifers. These regional contrasts suggest that scarcity-weighted water metrics would be particularly informative for Indian assessments, but no such assessment of milk or plant-based beverages in India was identified.

5.3 The Indian plant-based milk market (industry evidence)

Market estimates come entirely from Tier C sources and should be read as indicative. An industry outlook based on secondary research, expert interviews and consumer surveys estimated India's plant-based foods market at about ₹300 crore (around US\$36 million) in 2024, having grown at about 18 per cent a year between 2022 and 2024 and representing less than 0.1 per cent of the traditional dairy and meat market (Ipsos & PBFIA, 2025). The plant-based dairy segment was estimated at ₹210 crore in FY 2024, led by soy milk (45 per cent), almond milk (31 per cent) and oat milk (12 per cent) (Ipsos & PBFIA, 2025). A separate estimate placed the plant-based dairy category at about ₹250 crore and modelled export potential for Indian plant-based dairy at ₹459–1,889 crore by 2030 (GFI India, 2023). The divergence between estimates illustrates their uncertainty (Table 6; Figure 3).

Table 6: Snapshot of the Indian plant-based milk market (Tier C evidence)

Indicator	Value	Method	Source
Plant-based foods market, 2024	₹300 crore (~US\$36 million); ~18% annual growth, 2022–24	Industry analysis and expert interviews	Ipsos & PBFIA (2025)
Plant-based dairy segment, FY 2024	₹210 crore	Industry analysis and expert interviews	Ipsos & PBFIA (2025)
Share by product, FY 2024	Soy 45%; almond 31%; oat 12%; other 12%	Industry analysis and expert interviews	Ipsos & PBFIA (2025)
Plant-based dairy category (alternative estimate)	~₹250 crore	Industry estimate	GFI India (2023)
Export potential of plant-based dairy, 2030	₹459–1,889 crore	Scenario model	GFI India (2023)

Note: Market estimates are not independently verified and differ between sources.

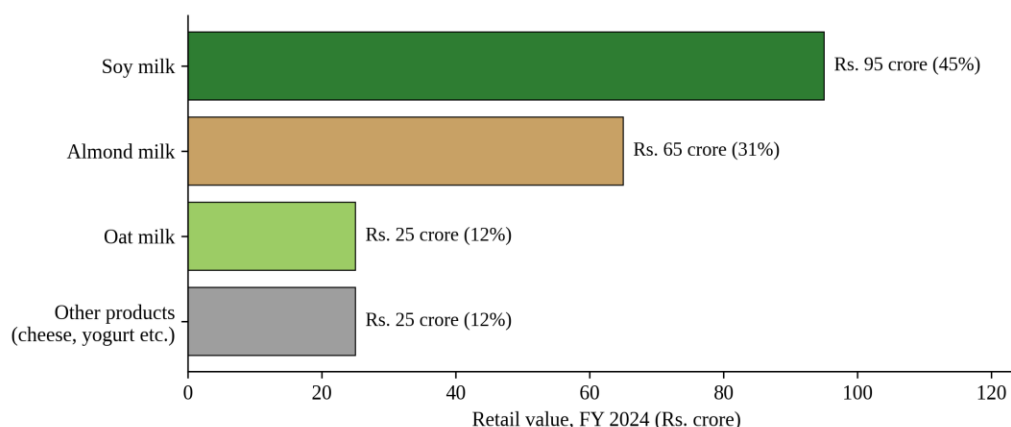


Figure 3: Composition of India's plant-based dairy market by product type, FY 2024 (total ₹210 crore).

Source: Ipsos & PBFIA (2025).

5.4 Indian consumers (industry survey evidence)

Two industry surveys provide the available consumer evidence; both used online, non-probability samples from large cities and are not nationally representative. In the first, an online panel survey of adults aged 18–65 in Tier 1 and Tier 2 cities (189 plant-based milk users and 99 non-users), 90 per cent of plant-based milk users had also consumed animal milk in the previous year and 65 per cent were using both at the time of the survey (GFI India & Ipsos, 2020). Health and well-being were the leading purchase drivers for both types of milk; plant-based milks were rated higher on sustainability and suitability for lactose intolerance, and dairy higher on taste, price and versatility. About 69 per cent of users expected to increase their consumption.

In the second, a 2025 survey of 220 plant-based food consumers in the eight largest metropolitan cities (NCCS A, aged 18–60, online mobile panel), daily use was reported by 62 per cent of animal milk users ($n = 112$), compared with 7 per cent of almond milk users ($n = 75$) and 8 per cent of soy milk users ($n = 61$) (Ipsos & PBFIA, 2025). Nutritional value (34 per cent) was the leading reason for choosing plant-based dairy, followed by lactose intolerance (11 per cent) and taste (9 per cent); 63 per cent purchased online, and respondents who had not consumed plant-based products in the previous three months (sample size not reported) most often described them as unnecessary, expensive or poor in taste and texture.

5.5 Policy and regulation

The Food Safety and Standards (Vegan Foods) Regulations, 2022 define vegan foods and require products labelled as vegan to be approved by FSSAI and to carry a designated logo (FSSAI, 2022); the regulations have since been amended. India has announced a net-zero target for 2070 (MoEFCC, 2022a), and its updated Nationally Determined Contribution states that it does not bind the country to sector-specific mitigation obligations, including in agriculture (MoEFCC, 2022b). Voluntary, market-led changes in production and consumption are therefore likely to be the main routes through which dairy and plant-based milk footprints are addressed in the near term.

6. Nutritional and Price Considerations

Per-litre comparisons treat a litre of each beverage as equivalent, although they differ markedly in nutrient content. Among almond, soy, rice and coconut beverages, soy was found to be nutritionally closest to cow's milk (Vanga & Raghavan, 2018). A cross-sectional analysis of 148 plant-based beverages from the United States, Australia and Western Europe found wide variation in protein, calcium, vitamin and sugar content between types and brands (Craig & Fresán, 2021). A label-based audit of 251 plant-based milk alternatives in 11 countries, published by an organisation that promotes alternative proteins, reported that most were fortified with calcium, commonly at 120 mg per 100 ml, were low in sugar, and contained less fat and saturated fat than cow's milk (Gallani & Klapp, 2024).

Iodine is a notable gap. Analysis of 47 milk-alternative drinks sold in the United Kingdom found that only three were fortified with iodine and that the median iodine concentration of unfortified drinks was 7.3 µg/kg, about 1.7 per cent of the value for conventional winter cow's milk (438 µg/kg) (Bath et al., 2017). In India, where iodised salt is the main vehicle for

dietary iodine, the public-health significance of this gap may differ, but it has not been assessed. WWF-UK (2022) recommends that plant-based milks be fortified at a minimum with calcium, vitamin D, vitamin B₁₂ and iodine.

Nutrient-adjusted metrics can change the ranking of beverages. Using an index of nutrient density relative to climate impact, Smedman et al. (2010) reported a value of 0.54 for milk and below 0.1 for oat drink; however, three of the authors were funded by a dairy council, and the index was criticised because its construction and nutrient weighting strongly influence the results (Scarborough & Rayner, 2010). Coluccia et al. (2022) found that, at Italian retail prices, soy drink cost about 66 per cent more than cow's milk per unit of protein. Taken together, these studies indicate that the GHG advantage of soy beverages is relatively robust to the choice of functional unit, whereas that of low-protein beverages is more sensitive to it. Table 7 illustrates nutrient and price differences for specific products in one market.

Table 7: Nutrient content and retail price of selected unsweetened dairy and plant-based milks (per 240 ml serving, USA)

Milk	Energy (kcal)	Protein (g)	Calcium (mg)	Potassium (mg)	Vitamin B ₁₂ (µg)	Price (US\$ per gallon)
Whole cow milk	152	8	306	374	1.34	3.39
Soy beverage	80	7	300	350	3.0	8.19
Oat beverage	90	2	350	400	0.2	9.45
Almond beverage	30	1	450	170	—	6.29

Source: Healthy Eating Research (2025), based on USDA FoodData Central values for named products and grocery prices in Durham, North Carolina, July 2024 (Tier C; illustrative only). Calcium in plant beverages is added through fortification.

Price is a recurring constraint. In the United States, plant-based milk cost on average 104 per cent more than dairy milk per gallon in 2023 (GFI, 2024), and Indian survey respondents cite cost as a leading barrier (Ipsos & PBFIA, 2025). For children, expert guidance identifies unsweetened, fortified soy or pea beverages as the only plant options nutritionally similar to cow's milk (Healthy Eating Research, 2025).

7. Implications for Indian Agribusiness

The evidence does not support framing plant-based milks as a replacement for Indian dairying. Dairy is a major source of income for smallholder and landless households, Indian consumers in the available surveys add plant beverages to their purchases rather than abandoning milk, and the India-specific environmental evidence needed for firm substitution claims is lacking. Instead, the evidence points to a two-track pathway: lowering the emission and water intensity of dairy production (Track 1) while developing farmer-linked plant beverage value chains based on crops already suited to Indian conditions (Track 2). Table 8 maps these tracks to specific stakeholders, the strength of the supporting evidence and the main constraints.

Table 8: Agribusiness opportunities by stakeholder, with evidence basis and constraints

Stakeholder	Opportunity	Evidence basis (confidence)	Main constraints
Dairy farmers and cooperatives (Track 1)	Raise yield per animal; ration balancing; efficient fodder irrigation; biogas from dung	FAO (2010); Gerber et al. (2013); Dixit & Birthal (2016) (moderate to high)	Adoption cost; extension reach; no Indian per-litre baseline
Soybean and millet growers and FPOs (Track 2)	Supply beverage-grade soybean and millets; primary processing into soy and millet bases	Poore & Nemecek (2018) for soy (high); millet beverages untested (low)	Quality specifications; aggregation; price volatility
MSMEs and start-ups	Fortified, unsweetened products using regional	Bath et al. (2017); Craig & Fresán (2021); Vanga	Price parity; taste; fortification and

	ingredients; transparent nutrient labels	& Raghavan (2018) (moderate)	compliance costs
Dairy processors	Hybrid portfolios using existing distribution and brand trust	Dual use of dairy and plant milk in surveys (low)	Naming and labelling rules; cannibalisation of dairy sales
Retail and e-commerce	Online channels to reach urban early adopters	63% online purchase in one survey, n = 220 (low)	Metro-only, non-representative evidence
Research institutions and policymakers	India-specific LCAs, nutrient-adjusted comparisons, consumer studies; support for micro food processing	Evidence gaps identified in this review	Funding; data access; coordination across livestock and crop research

Source: Synthesised by the authors from the evidence reviewed.

Rajasthan illustrates both tracks. As the second-largest milk-producing state (DAHD, 2024) with documented groundwater depletion (Rodell et al., 2009), it has a strong case for improving the water and emission efficiency of dairying. Its rain-fed pearl millet and soybean production also offers raw-material bases for Track 2, provided that local processing, fortification and quality standards can be achieved at competitive cost. For agribusiness management, the immediate priorities are value chain analyses of beverage-grade soybean and millet supply through farmer producer organisations, and cost-benefit assessments of efficiency measures in smallholder dairying.

8. Strength of Evidence, Limitations and Research Gaps

8.1 Strength of evidence

Table 9 summarises the confidence assigned to the main findings using the criteria in Section 2.6. Confidence is high for the global per-litre GHG and land comparisons, moderate for nutrient-related findings, and low for most India-specific market and consumer findings.

Table 9: Summary of key findings and confidence ratings

Finding	Main sources	Confidence
Per litre, soy, oat and almond beverages have lower GHG emissions (~69–78%) and land use than cow's milk	Poore & Nemecek (2018); Berardy et al. (2022); Coluccia et al. (2022); Ramsing et al. (2023)	High
Freshwater-withdrawal savings are large for soy and oat but modest for almond beverages	Poore & Nemecek (2018); Ramsing et al. (2023)	High
Water comparisons depend on the metric used	Hoekstra et al. (2011); Mekonnen & Hoekstra (2012); Boulay et al. (2018)	High
Dairy emission intensity is higher in low-yield systems such as South Asia	FAO (2010); Gerber et al. (2013)	High
Enteric fermentation dominates Indian agricultural emissions; buffaloes contribute disproportionately	MoEFCC (2021); Dixit & BIRTHAL (2016)	High (inventory); moderate (buffalo share)
Fortified soy beverages are nutritionally closest to milk; many plant beverages lack iodine	Vanga & Raghavan (2018); Craig & Fresán (2021); Bath et al. (2017)	Moderate
Advantage of low-protein beverages	Smedman et al. (2010); Coluccia et al.	Moderate (method-

narrows on a nutrient basis	(2022); Scarborough & Rayner (2010)	dependent)
Indian plant-based dairy ≈ ₹210–250 crore, led by soy milk	Ipsos & PBFIA (2025); GFI India (2023)	Low
Indian plant-milk users largely continue to consume dairy; price and taste are barriers	GFI India & Ipsos (2020); Ipsos & PBFIA (2025)	Low
Environmental performance of millet beverages	No peer-reviewed LCA identified	Unknown

8.2 Limitations of the evidence

The evidence base has several limitations. Most LCAs come from Europe and North America and concern cow's milk, whereas Indian milk comes substantially from buffaloes in smallholder mixed systems. Global means conceal wide variation between producers. Studies use different functional units, system boundaries and global warming potential values, and water results are reported in non-comparable metrics. Peer-reviewed LCAs of oat beverages are fewer than those of soy and almond beverages, and none was identified for millet beverages. Nutrient evidence relies largely on label data from Western markets. Indian market and consumer evidence comes from industry and advocacy organisations, uses small, urban, non-probability samples, and in the case of market size cannot be independently verified. Several sources have potential conflicts of interest, in both directions.

8.3 Scope and Limitations of the Review

This review is a structured narrative review rather than a systematic review. Screening and data extraction were conducted by the authors without formal inter-rater reliability assessment; only English-language sources were considered, and publication bias cannot be excluded. Environmental comparisons rely primarily on a single global dataset, selected because it reports all four products using a common methodological framework. Market estimates are time-sensitive and were not adjusted for inflation.

8.4 Research gaps

Table 10 sets out the research gaps identified in this review and suggests study designs suited to Indian agricultural universities and research institutes.

Table 10: Research gaps and suggested study designs

Research gap	Why it matters	Suggested study design
LCA of cow and buffalo milk across Indian production systems and agro-climatic zones	No India-specific per-litre baseline for comparison	ISO 14040/14044 attributional LCA using farm surveys and national inventory factors
LCA of soy and millet beverages produced in India	Environmental claims for Indian products are untested; millet beverages unassessed	Cradle-to-retail LCA of pilot and commercial units, including scarcity-weighted water use
Nutrient-adjusted comparisons for Indian diets	Per-litre comparisons ignore nutrient differences	Functional units based on Indian dietary reference values; sensitivity analysis
Representative consumer evidence and willingness to pay	Existing surveys are small, urban and non-probability	Choice experiments or contingent valuation with probability samples across city tiers and rural areas
Economics of beverage-grade soybean and millet supply through FPOs	Farmer benefits of Track 2 are unknown	Value chain analysis, cost–benefit analysis and price transmission studies

Water-scarcity assessment of fodder and beverage crops in arid districts	Location strongly affects water impacts	Regional AWARE-based assessment for Rajasthan and other water-stressed states
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Source: Developed by the authors.

9. Conclusion

This review addressed four questions. On RQ1, global LCA evidence indicates with high confidence that, per litre, soy, oat and almond beverages generate about 69–78 per cent less GHG emissions and use substantially less land than cow's milk; freshwater-withdrawal savings are large for soy and oat beverages but modest for almond beverages, and water comparisons are valid only within a single metric. On RQ2, these advantages narrow on a nutrient basis and depend on fortification; fortified soy beverages are the plant option nutritionally closest to milk, and the extent of the trade-off depends on the functional unit chosen. On RQ3, India-specific evidence confirms that enteric fermentation dominates agricultural emissions and that groundwater stress is severe in major dairy states, but no Indian LCA comparing dairy and plant-based milks was identified, and market and consumer evidence rests on industry sources with small, urban samples. On RQ4, the evidence supports a two-track pathway, improving the emission and water intensity of dairy while developing fortified, farmer-linked soybean and millet beverage value chains, rather than substitution of dairy. Priority research includes India-specific LCAs of cow, buffalo, soy and millet milks using consistent metrics, nutrient-adjusted comparisons, and representative studies of consumer demand and farm-level economics.

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