# Environmental Footprint of Dairy-Based Agriculture: Indicator-Based Assessment and Mitigation Approaches

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***Abstract—*** *Environmental sustainability is a key component of resilient agricultural systems, particularly in integrated dairy-based farming where livestock interacts closely with the ecosystem. This study assesses environmental sustainability through nine indicators: animal health, housing conditions, calf raising, use of dung, water management, drought preparedness, disposal of packaging, urine management, and animal carcass disposal. Based on responses from 100 dairy farmers, findings show that while indicators such as animal health and dung use scored high, weaknesses were noted in drought preparedness, water management, and waste disposal. The Environmental Sustainability Index (EnSI) for the farms ranged from 0.22 to 0.84, with the majority categorized as moderately sustainable. These results underline the importance of targeted interventions to enhance sustainability in dairy-based systems.*

***Keywords— Environmental sustainability, Indicators, Dairy farming, Kumaon, Uttarakhand.***

## I. INTRODUCTION

Human beings have long had an inherent tendency to conserve resources for future generations. This instinct has helped sustain nature and natural resources since prehistoric times. However, in the past two centuries, the Earth's ecosystem has faced unprecedented pressure due to rapid population growth, industrialization, and urbanization. The sudden rise in population in certain regions, combined with expanding urban settlements and industrial activities, has triggered significant strain on natural resources. This situation compels us to critically examine whether our current model of development truly leads us toward progress—or whether it misguides us away from sustainability. Sustainability refers to the responsible and balanced use of resources in a manner that meets present needs without compromising the ability of future generations to meet theirs. It is commonly conceptualized through three interdependent pillars: economic**,** social**,** and environmental sustainability. While the debate continues over which pillar is most critical, it is now widely acknowledged that over-exploitation of natural resources today will make life more difficult for future generations. Dairy farm sustainability issues are often categorized as either economic, environmental or social (von Keyserlingk et al., 2013) However, how to precisely define, how to measure, and how to operationalize sustainable development in various societal domains remain a work in progress within the scientific community (Gibbes et al., 2020; Ruggerio, 2021). In simpler terms, sustainability represents an informal contract between the current and future generations, ensuring that resources are preserved in their current form and availability for continued use.

India became the most populous country in the world in 2023, and its population is projected to grow further at least until 2050. Simultaneously, India is undergoing rapid urbanization. Projections indicate that by 2046, more than half of its population will live in urban areas. This demographic shift will significantly intensify the demand for limited resources, particularly food, water, and energy. The present moment is critical to reflect on whether our development trajectory aligns with the principles of sustainability. According to the United Nations, global food demand is expected to double by 2050, driven by a rising population—from 7.6 billion in 2017 to 8.6 billion by 2030, 9.8 billion by 2050, and more than 11.2 billion by 2100.

In front of tremendous changes in world population, arable land availability and all global climate activities must be directed to increase the overall food production by almost 70 % by 2050, corresponding to an annual increase of 1.75 % in productivity

to meet the future demand (Global Harvest Initiative. 2010). Only by following the principles of sustainability (Devendra, 2001) the most countries have a realistic chance to reach by 2050 the goal to produce demand related quantities of food.

Agricultural systems worldwide must respond to this surge in demand by increasing food production—while doing so in ways that are nutritious, healthy, and environmentally sustainable. The dairy sector, in particular, faces both opportunities and challenges in this regard. Dairy farming has historically been an integral part of human civilization, deeply embedded in social, cultural, and economic systems across the globe. Today, the growing emphasis on food and nutrition security has further increased the importance of dairy products. Milk and its derivatives are now essential dietary staples, found in nearly every household and kitchen. Dairy farming has rapidly intensified over the past 50 years (FAO 2018a). Current modes of dairy intensification are widely recognized to generate negative impacts along multiple dimensions: the environment (Del Prado et al. 2013), animal welfare (Koeck et al. 2014), human health (Westhoek et al. 2014), and rural livelihoods and well-being (Flaten 2002). Sustainable intensification, in brief, denotes an aim of increasing productivity while simultaneously decreasing the negative environmental effects of conventional farming practices (Garnett et al. 2013).

India, as the world's largest milk producer, contributes approximately 25% of global milk production. Meeting future demands, given India's growing population and consumption, will require a significant transformation of dairy practices. While dairy farming is well-integrated into rural livelihoods and contributes substantially to the national economy, its environmental consequences remain underappreciated.

The sustainability of dairy production systems is being undermined by several environmental challenges. These include greenhouse gas (GHG) emissions, water usage and contamination, and land degradation. As Hossain et al. (2025) note, such impacts threaten long-term ecological stability, while Basaragi and Kadam (2024) suggest that climate-smart practices and value-added dairy products offer potential pathways to sustainability. To preserve this fragile ecosystem, instead, there is a need to develop a dairy farming system which must be sustainable for the animal and the environment and economically feasible (Cozzi and Bizzotto, 2004). In 2015, global milk production reached 666.5 billion kilograms, an increase of 30% from 2005 levels. This increase led to an 18% rise in GHG emissions, primarily due to methane ($CH_4$), nitrous oxide ($N_2O$), and carbon dioxide ($CO_2$) emissions (FAO, 2019). The marked changes in our environment (e.g., climate, soil degradation, water quality and availability, deforestation, greenhouse gas emissions, waste quantity, biodiversity) indicate that conventional farming, at least to some extent, should be changed to sustainable production systems (Hamann, 2017). Dairy farming is also one of the most water-intensive food industries, contributing significantly to water pollution. Meena (2018) highlights the dairy industry's role in emitting harmful gases and degrading water quality. Furthermore, research by de Vries and de Boer (2010), and Milani et al. (2011) indicates that livestock production—including feed cultivation, transport, processing, and consumption—has a disproportionately large impact on climate change.

The environmental sustainability of dairy practices varies significantly across regions. A study by Singh et al. (2024) found that milk production in Punjab is more environmentally efficient than in Rajasthan. The study highlights cattle feed as a major contributor to environmental impacts, along with the choice of packaging materials used for processed milk. Achieving synergy between economic viability and ecological sustainability represents a fundamental challenge and opportunity for the dairy industry (Britt et al., 2018).

Dairy cattle, in particular, affect the environment through their emissions and waste products. According to Naranjo et al. (2020), these impacts extend across air, water, and land systems. The Central Pollution Control Board (CPCB, 2020) reports that a single bovine animal weighing around 400 kg produces approximately 15–20 kg of dung and 15–20 liters of urine per day—contributing to substantial environmental burdens when scaled across herds. It is also observed that only very few studies in India have addressed the environmental aspects of milk production, out of which one published study is from Anand Gujrat for the accounting carbon footprint of milk production by small farmers (Garg et al., 2016). Milk is a staple food, and its environmental impact study can guide the policymakers to devise eco-efficient policy for sustainable growth. Assessing the sustainability of milk production in India (the largest milk producer country in the world) is essential to ensure that the dairy industry can meet the growing demands for dairy products while minimizing its negative impact on the environment, society, and the well-being of the people involved in the sector (Singh et al. 2024). The sustainability indicators are composed of different indicators, such as: environmental (air quality, water quality, energy consumption), social (quality of life, well-being, income distribution), and economic (consumption and production pattern, liquidity), and can act jointly, forming indexes, or separately, in the three spheres that comprise sustainability (Goswami et al., 2017, Rawlikowska et al.,2019 and Mandart et al.,2019). Sustainability is a concept and cannot be measured directly. Appropriate indicators must be selected to determine levels and duration of sustainability (Zinck and Farshad, 1995). To address sustainability challenges in agriculture,

private and multi-stakeholder initiatives increasingly use sustainability indicators to monitor the sustainability impact of farms. These indicators can be part of standards for certification or assessment tools to measure farm performance. While these initiatives play an important role in navigating the sustainability transition, insight in how these governance initiatives operationalize sustainability in crop farming is lacking (Konefal et al., 2023)

In light of the environmental sustainability challenges associated with dairy farming, the present study was undertaken in the hilly state of Uttarakhand, India. The objectives of the study are:

1. To identify key environmental sustainability indicators relevant to dairy farming.
2. To assess these sustainability indicators in the context of hill farming systems.
3. To propose practical strategies and approaches for enhancing the environmental sustainability of dairy farming.

## II. RESEARCH METHODOLOGY

The present study was conducted to during the year 2024-25 in Kumaon region of Uttarakhand covering two districts viz Alomra and Pithoragarh selected randomly. Fifty dairy farmers from five randomly selected villages (Ten from each selected village) were interviewed directly with a pre-tested scientific questionnaire to collect information and draw inferences from a total sample size of hundred dairy farmers. The data collected was compiled, tabulated, analyzed and interpreted with statistical means and comparison.

## III. RESULT AND DISCUSSION

### 3.1 Environmental Sustainability:

Environmental sustainability of dairy farms was examined by considering the indicators i.e. Animal health, Housing conditions, calf raising condition, water management, preparedness to drought, Disposal of generated waste, urine, dung and dead animals disposal pattern which provide uncertainty and impose new constraints on product.

### 3.2 Environmental Sustainability Indicators:

Indicators are a subset of the many possible attributes that could be used to quantify the condition of a particular landscape, catchment or ecosystem (Walker 1998). In the present study following indicators were studied to draw environmental sustainability index.

#### 3.2.1 Animal Health:

Animal health is the basis of sustainable dairy farming practices. Sound health of reared animals not only makes dairy an economical venture but also contribute to sustainability of the business. Data presented in Table 1 reveals that majority of dairy farmers (76.00 percent) were taking care of animal health whereas only 24.00 percent dairy farmers were having casual approach towards animal health. Many researchers has highlighted the importance of animal health in sustainability. Animal health plays a vital role in sustainable livestock farming balancing three components-environmental responsibility, economic viability, and social acceptability (Capper, 2012, Kenyon et al. 2013). A fall in disease levels of 10 percentage points is associated with an 800 million tonne decrease in greenhouse gas (GHG) emissions (Oxford Analytica., 2021)

#### 3.2.2 Housing condition:

Proper housing which is conducive to good health, comfort and protection from inclement weather and which would enable the animals to utilize their genetic ability and feed for optimal production (TNAU, 2025). A data regarding housing condition of the animals is presented in Table 1. Distribution of respondents based on measure to check toxicity which reveals that most of the farmers (75.00 percent) were providing satisfactory housing conditions to their animals whereas 25.00 percent farmers were keeping their animals in open and kachha floors. An explanation towards this phenomenon might be higher exposure of SHG members to dairy farming trainings, media exposure and extension contacts.

#### 3.2.3 Calf raising conditions:

Improving health and welfare outcomes for replacement and surplus dairy calves is important for the sustainability of the dairy industry. Table 19 reveals that majority of dairy farmers (75.00 percent) are taking care of calf raising conditions and providing necessary vaccinations to calves whereas only 15.00 percent dairy farmers were having casual approach in this regard.

### 3.2.4 Use of dung as manure over fuel:

Cow dung is a very serious problem for people around the farm. The problem is often caused by cow dung which is not handled professionally (Ratminingsih and Jumadi, 2020). India's soils are getting depleted of organic matter. If application of organic manure and such other sources to soil is not increased, the country will face serious sustainability challenges (NITI Aayog, 2023). Dung is created in dairy farming and its purposeful and sustainable use help in environmental stability. Study data presented in Table 1 reveals that 95 percent of the farmers were using dung as manure rather than direct fuel 5 percent.

**TABLE 1**
**ENVIRONMENTAL SUSTAINABILITY INDICATORS FOR DAIRY FARMS**

| Respondents (n=100) | Category | |
|---|---|---|
| Animal health management | Not-Satisfactory (0-3) | Satisfactory (>3) |
| | 24 **(44.00)** | 76 **(56.00)** |
| Housing conditions of animals | Not-Satisfactory **(0-3)** | Satisfactory **(>3)** |
| | 25 **(25.00)** | 75 **(75.00)** |
| Calf raising conditions | Vaccinated **(0)** | Not Vaccinated **(1)** |
| | 85 **(85.00)** | 15 **(15.00)** |
| Use of dung as manure over fuel | Dung as fuel **(0)** | Dung as manure **(1)** |
| | 5 **(05.00)** | 95 **(95.00)** |
| Water Management | Not-Satisfactory **(0)** | Satisfactory **(1)** |
| | 62 **(62.00)** | 38 **(38.00)** |
| Preparedness to drought | Not-Satisfactory **(0)** | Satisfactory **(1)** |
| | 82 **(82.00)** | 18 **(18.00** |
| Disposal of medicine and feed packaging | Not-Satisfactory **(0)** | Satisfactory **(1)** |
| | 60 **(60.00)** | 40 **(40.00)** |
| Animal urine disposal | Not-Satisfactory **(0)** | Satisfactory **(1)** |
| | 66 **(66.00)** | 34 **(34.00)** |
| Disposal of animal bodies in case of death | Not-Satisfactory **(0)** | Satisfactory **(1)** |
| | 0 **(0.00)** | 100 **(100.00)** |

***(Figure in parenthesis indicate percent)***

### 3.2.5 Water Management:

Milk production needs a high quantity of water, which may have a significant impact on the cost of production as well as potential negative effects on the environment. At the dairy farm, water is commonly used for drinking, cooling systems, washing facilities and equipment, irrigation, and domestic use (IHDB, 2015). Dairy farmers can reduce their water footprint by implementing practices that can include proper feeding of animals and monitoring of water consumption, adequate ventilation of facilities, as well as maintenance and repair of water, wastewater, and irrigation systems. Proper water

management in dairy farms is important to prevent pollution from fertilizers, pesticides etc. The water management conditions of dairy farms of the respondents is depicted in Table 1.

Water management practices followed by 62 percent faremrs were not-satisfactory whereas 38 percent dairy farmers found following satisfactory water management practices in the study area. Similar trends were reported by Singh &Hansra (2021) and Rahman (2011).

### 3.2.6 Preparedness to drought:

Irrigation water is crucial for dairy farming. Dairy farming is an intensive agriculture with requirement of water to sustain farm potential. Dairy farming is practiced on steep hill farms in study area where it is very much required that dairy farms are prepared for irregular water supply and erratic rainfall. Analysis of data presented in Table 1, reveal that majority of the respondents (82.00 per cent of dairy farmers) were not prepared for drought whereas only 18 percent farmers have preparedness to drought. Singh & Hansra (2021) and Rehman (2011) observed similar trends for preparedness of flood in a research conducted in Himachal Pradesh and Assam respectively.

### 3.2.7 Disposal of medicine and feed packaging:

Analysis of data reveals that majority of the respondents 60.00 per cent of farmers were disposing old medicine and feed packaging in very casual way which is not satisfactory whereas only 40.00 percent dairy farmers were found to dispose medicine and feed packaging in satisfactory way.

### 3.2.8 Animal urine disposal:

Urine from dairy animals, a byproduct of the livestock industry, raises environmental concerns due to its potential to pollute water sources and release greenhouse gases. Improper disposal can clog drainage systems, contaminate water supplies, and create breeding grounds for disease-carrying pests. The management of animal urine on dairy farms is a key indicator of environmental sustainability, as it has a direct impact on both water quality and greenhouse gas emissions. Analysis of data reveals that animal urine was disposed –off in open in un-satisfactory way by majority of the respondents (66.00 per cent) whereas only 34.00 percent of the dairy farmers were found to have satisfactory urine underground disposal system.

### 3.2.9 Disposal of animal bodies in case of death:

Dead animals are potentially dangerous because their death may be caused by infection with contagious diseases, like the bacteria that live on the flesh and wool of dead animals. These microbes can resist the harsh external environmental conditions for several years. These microbes may spread via air, which means increasing the scope of contamination. (Dead animals, 1995; Ristić et al., 2013). Death animals' bodies' decomposition add harmful gases to the environment and release toxic substances which is threat to environmental sustainability. Hence way to dispose dead animals is also an important indicator of environmental sustainability of dairy farms. In present study data was collected about handling dead animals ie buried at proper place (satisfactory) or kept in an isolated place (un-satisfactory). As data placed in Table 1 reveal that 100 percent of the farmers were disposing dead animal to the satisfactory level.

**TABLE 2**
**ENVIRONMENTAL SUSTAINABILITY INDEX (ENSI) OF DAIRY FARMS**

| Respondents | Level of sustainability | | | |
|---|---|---|---|---|
| | Least Sustainable (0-0.25) | Moderately Sustainable (0.26-0.50) | Sustainable (0.51-0.75) | Highly sustainable (0.76-1.00) |
| Members (n=100) | 3 **(3.00)** | 51 **(51.00)** | 42 **(42.00)** | 4 **(4.00)** |

***(Figure in parenthesis indicate percent)***

### 3.3 Environmental sustainability of dairy farms of the respondents:

To find out environmental sustainability index (EnSI) of the farms, the above discussed indicators were used and data is presented in Table 2. The EnSI of dairy farms range from 0.22 to 0.84. Majority of the dairy farms (51.00 percent) were found moderately sustainable followed by sustainable farm (42.00 %). Leishangthem et al (2017) also reported majority of farms in moderate category of sustainability and similar trend of results reported by Singh and Hansra (2021), Rehman (2011) for farming studies

## IV. CONCLUSION

The environmental sustainability of dairy farms is a complex yet critical concern, especially in regions where traditional practices intersect with modern demands. This study, by employing key indicators such as animal health, housing conditions, calf rearing, water management, drought preparedness, waste disposal methods, and manure usage, provides a comprehensive overview of sustainability practices followed by dairy farmers. The findings reveal that while certain aspects—like animal health care (76%), calf raising (85%), use of dung as manure (95%), and proper disposal of dead animals (100%)—are being addressed with commendable diligence, other indicators demonstrate significant gaps. Notably, areas such as drought preparedness (only 18% satisfactory), water management (38%), and disposal of medicine/feed packaging and animal urine remain weak points that require immediate attention. The Environmental Sustainability Index (EnSI) calculated in the study further emphasizes these disparities. With 51% of farms categorized as moderately sustainable and only 4% reaching high sustainability, it is evident that most farms operate below optimal environmental standards. These results align with previous research, confirming that environmental sustainability in dairy farming remains an area needing concerted policy support, technological intervention, and farmer awareness. In conclusion, while there is encouraging progress in some practices, comprehensive improvement across all indicators is essential. Strengthening education and extension services, promoting eco-friendly technologies, and enhancing access to sustainable infrastructure will be pivotal in transitioning more dairy farms towards higher environmental sustainability. Only with integrated, science-based efforts can the dairy sector ensure long-term ecological balance while sustaining livelihoods.

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