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# From Cow to Climate: Tracing the Path of Dairy Sustainability: Unveiling the Impact on Sustainable Development Goals through Bibliometric and Literature Analysis

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*Article*

# From Cow to Climate: Tracing the Path of Dairy Sustainability: Unveiling the Impact on Sustainable Development Goals through Bibliometric and Literature Analysis

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**Abstract:** Dairy farming dates to the early Neolithic era in Europe, Middle East, Asia, and Africa. Over time, the industry has evolved from small ranches and farmhouses milk processing units to large, intensive dairy farms and big, high-tech processing units. Despite the industry's contribution to the economy and food production, multiple studies have tainted cattle farming as a main contributor to climate change. This study explores literature in dairy farming and sustainable development goals (SDGs) to identify current scholarly developments since the formulation and adoption of SDGs in 2015 and themes for future research. This paper argues that dairy animals are not the source of sustainability shortfalls as depicted by multiple scholarly articles, but human processes associated with dairy farming. Data was analyzed using R package, Excel, NVIVO, and VoS Viewer. A review of literature shows that dairy farming and its contribution to sustainability has gained more intensive scientific interest since 2015. Moreover, livestock management, feed production and management, stakeholder's management, logistics and supply chain management, and waste management are the sources of environmental adversities associated with dairy farming. Notably, these are human processes developed from commercialization of dairy farming and involve multiple stakeholders across the supply chain. While solutions are embedded within these processes, innovation emerges as a key driver of sustainability and source of opportunities to strengthen sustainability in dairy farming sector and achieve the sustainable development goals.

**Keywords:** dairy farming; sustainability; sustainable development goals; bibliometric analysis; sustainable practices; environmental impact; milk production

## 1. Introduction

The dairy industry is a source of revenue, food, and employment to the global economy. More specifically, it benefits the world by providing milk and other dairy products. However, despite the multiple benefits associated with this industry, it has been implored for its potential adverse impacts on the environment. This section begins by exploring the shortcomings associated with dairy farming in relation to sustainable development to develop an understanding of how the sector affects the environment. In the subsequent section, it explores the strategies proposed by numerous studies to address the sustainability shortcomings.

The dairy sector has been identified as a major source of greenhouse gas emissions through waste and enteric fermentation. Dairy cattle excrete nitrogen emissions through their urine and fecal matter. The United Nations' (UN) Food and Agriculture Organization estimates that the sector account for 4.9% of the total human-induced emissions [1]. Additionally, production processes in this industry pollute water and air, and contribute heavily to deforestation and soil degradation. In addition to ecological destruction, the industry has been criticized for immense animal suffering both physically and mentally for the sake of milk production.

The last thirty years have been characterized by extreme and massive increases in temperature. This period has been the warmest in the history of the earth [2]. Besides the surge in temperature, the world has also experienced other major changes to the climate, such as rising sea levels, increasing ocean temperature, extreme weather events and related disasters, and substantial rises in the emission of greenhouse gases. The last few years have been marked by increases in the oceanic uptake of carbon, resulting in ocean acidification and reduction in the surface water pH [3]. These changes primarily result from anthropogenic emissions of greenhouse gases that have steadily risen since the commencement of the industrial revolution in the 1750s [4]. Livestock farming, including the phases of growing, processing, transport, and consumption have a relatively significant impact on climate change.

Predominantly, dairy cattle have been demonstrated to impact land, water, and air adversely. In terms of air quality, the industry accounts for 2.9% of global emissions, which is a significant percentage [5]. Apart from carbon emissions, dairy farms account for other forms of air pollution, including ammonia emissions, which are associated with milk production processes. The enteric fermentation and manure processes also compromise air quality by producing methane [6]. As potent greenhouse gases, carbon, ammonia, and methane are highly effective in rapping heat in the atmosphere, a core factor contributing to global warming. These emissions also contribute to the development of particulate matter and secondary aerosols, which adversely affect the environment and human health.

The adverse impacts of dairy farming processes also extend to water quality and land degradation. The processes involved in dairy farming affect the quality of water by discharging pathogens, nutrients, and other contaminants into water bodies [5]. Discharge occurs in the form of runoff from dairy cows. Besides contaminating water, runoff causes eutrophication by releasing nutrients like phosphorus and nitrogen into nearby waterways. Eutrophication causes algal blooms that result in the depletion of oxygen levels in water bodies [5]. In addition to killing fish and other marine animals, eutrophication compromises the entire aquatic ecosystem. Intense dairy farming practices are often linked to land degradation issues due to the overuse of synthetic fertilizers and manure [6] . This often results in soil compaction, erosion, and nutrient imbalances. These adverse effects caused intense pressure to embrace sustainable practices to not only mitigate them but also foster ecological stewardship in addressing the global warming issue.

There are multiple strategies that numerous studies have proposed to address sustainability issues in dairy farming. They include Sustainable intensification, multifunctional agriculture, and agroecology. Each of these strategies is explained in sections 1.1, 1.2, and 1.3 respectively.

### *1.1. Sustainable Intensification*

One recommended tactic for eliminating the shortcomings and mitigating the dairy sector's adverse impact on the environment is sustainable intensification (SI). SI is a strategy that acknowledges the need to intensify food production to satisfy the expanding demand [7]. It recognizes the negative ecological impacts of agricultural production on the environment and seeks to increase food production without encroaching on both resource and the environment by highlighting the significance of expanding productivity per unit land. Similar to these findings Huang et al. asserts that SI strategies in dairy farming target ecological issues, such as minimizing greenhouse emissions by breeding cows in a manner that reduces the emission of methane and planting feeds that require less nitrogen fertilizers [8].

This strategy resonates with the sustainable development goals (SDG) zero hunger, clean water and sanitation, climate action, and responsible consumption and production. The SDG 2, Zero Hunger, seeks to improve accessibility to food for all global population. Therefore, by utilizing sustainable practices like optimized feed efficiency to improve the productivity of dairy cattle, SI

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contributes to the second SDG [9]. It achieves this by improving food production and safeguarding food security. For Clean Water and Sanitation (SDG 6) and Climate Action (SDG 13), SI fosters responsible water use, minimizes water pollution, curtails the emission of greenhouse gases, and increases carbon sequestration as asserted [8].The strategy aligns with the core objectives of responsible consumption and production (SDG 12) as it fosters the optimization of resources and minimizes waste. Dairy farmers align with the principles of responsible production and consumption patterns by utilizing SI practices to reduce food waste and improve productivity.

### *1.2. Multifunctional Agriculture*

Besides SI, the other development that has emerged in this sector to foster ecological sustainability efforts is multifunctional agriculture. It is a non-productivism paradigm that restructures rural landscape to allow diverse services beyond agricultural production [10]. This strategy usually reintegrates agriculture with rural development initiatives, such as poverty reduction, and merges them with environmental conservation. The approach fosters the shift from a sectoral focus on agriculture to a more holistic emphasis on regions [11]. It enables policy makers to address human-environmental elements of multifunctional landscapes, such as diversification of livelihoods. Thus, it best resonates with the first SDG, which seeks to eliminate poverty, SDG 10 (reduced inequalities), and SDG 5 (gender equality).

In relation to SDG 1 (No Poverty), the multifunctional agriculture strategy contributes to the eradication of poverty by providing farmers, especially small scale, the opportunity to venture into diverse livelihoods and income sources. It achieves this by incorporating multiple functions, such as rural development, food production, and ecosystem services. The 10th SDG (Reduced Inequalities) relates to this strategy by fostering more equitable and inclusive rural development. It supports smallholder farmers and marginalized groups like women and indigenous communities by increasing their access to opportunities and resources [11]. Therefore, by supporting women, multifunctional agriculture also aligns with the gender equality sustainable development goal (SDG 5). It empowers women to participate in agriculture.

### *1.3. Agro-Ecology*

Agroecology is a development that fosters ecological sustainability in the dairy sector. According to Clay et al., this strategy dates to the 1930s and it can be defined both as a scientific approach and a social movement/practice [7]. It fuses ecology and agronomy to develop a sustainable food system. As both a social movement and scientific discipline, agro-ecology accentuates the integration of social and natural science, practical engagement with activist group, and close interactions with farmers to catalyze social change [12]. It is widely recognized as the most appropriate strategy to address the unbalanced power dynamics that inform dairy intensification trends. Therefore, it resonates with industry, innovation, and infrastructure (SDG 9), reduced inequalities (SDG 10), life below water (SDG 14), and life on land (SDG 15).

Agro-ecology aligns with the core aspects of SDG 9 by fostering innovation in the dairy sector in the form of sustainable farming practices. In reducing inequalities (SDG 10), the practice promotes more equitable and inclusive farming practices. It achieves this by empowering smallholder farmers and marginalized communities and increasing their access to resources. Therefore, it minimizes agricultural productivity and income disparities [7]. SDG 14 and 15 address environmental pollution directly since they advocate for the conservation of both marine and freshwater ecosystems and biodiversity. Agro-ecology promotes practices that not only reduce the use of agrochemicals but also promotes farming practices like agroforestry [12]. Therefore, the practice helps to preserve ecosystem and aquatic biodiversity by reducing water pollution, contamination, and agricultural runoff.

To explore current developments in dairy farming, the research seeks to address the following research questions.

RQ1. What are the publication trends in dairy farming and sustainability from 2015 to 2023?

RQ2. Who are the most prolific scholars, articles, Journals, and countries contributing to dairy farming and sustainable development from 2015 to 2023?

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RQ3. What are the research themes from the literature review and areas for future research?

## 2. Materials and Methods

The research will draw data from SCOPUS and Web of Science, which are widely used and reliable sources of scientific publications in social sciences. These sites are credited for broader coverage and citation count. Multiple software packages will be used for data analysis namely Bibliometric R package, VoS Viewer, Nvivo, and Excel. The bibliometric R package and VoS Viewer will be used for bibliometric analysis, Nvivo for thematic analysis of the top ten articles, and Excel for charts.

The Key word "dairy sector", "dairy industry" OR "milk production" OR "livestock farming" "sustainability", "sustainable development goals" and "SDGs" occurring in the abstract, keywords, and titles were used to extract publications from both SCOPUS and Web of Science. They were limited to articles published from 2015 in English and relevant research fields.

The exact research keyword combination was.

( TITLE-ABS-KEY ( ( "dairy sector" OR "dairy industry" OR "milk production" OR "livestock farming" ) ) AND TITLE-ABS-KEY ( ( "sustainability" OR "sustainable development goals" OR "SDGs" ) ) ) AND PUBYEAR > 2015 AND ( LIMIT-TO ( SRCTYPE , "j" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) ) AND ( EXCLUDE ( PUBYEAR , 2024 ) ) AND ( LIMIT-TO ( SUBJAREA , "AGRI" ) OR LIMIT-TO ( SUBJAREA , "VETE" ) OR LIMIT-TO ( SUBJAREA , "SOCI" ) OR LIMIT-TO ( SUBJAREA , "BUSI" ) OR LIMIT-TO ( SUBJAREA , "ENVI" ) ) AND ( LIMIT-TO ( EXACTKEYWORD , "Sustainability" ) OR LIMIT-TO ( EXACTKEYWORD , "Cattle" ) OR LIMIT-TO ( EXACTKEYWORD , "Milk Production" ) OR LIMIT-TO ( EXACTKEYWORD , "Dairy Farming" ) OR LIMIT-TO ( EXACTKEYWORD , "Milk" ) OR LIMIT-TO ( EXACTKEYWORD , "Sustainable Development" ) OR LIMIT-TO ( EXACTKEYWORD , "Dairying" ) OR LIMIT-TO ( EXACTKEYWORD , "Dairy Industry" ) OR LIMIT-TO ( EXACTKEYWORD , "Dairy Cattle" ) OR LIMIT-TO ( EXACTKEYWORD , "Milk Yield" ) OR LIMIT-TO ( EXACTKEYWORD , "Dairy" ) OR LIMIT-TO ( EXACTKEYWORD , "Dairies" ) OR LIMIT-TO ( EXACTKEYWORD , "Farming System" ) OR LIMIT-TO ( EXACTKEYWORD , "Grazing Management" ) )

The search methodology is illustrated in Figure 1.

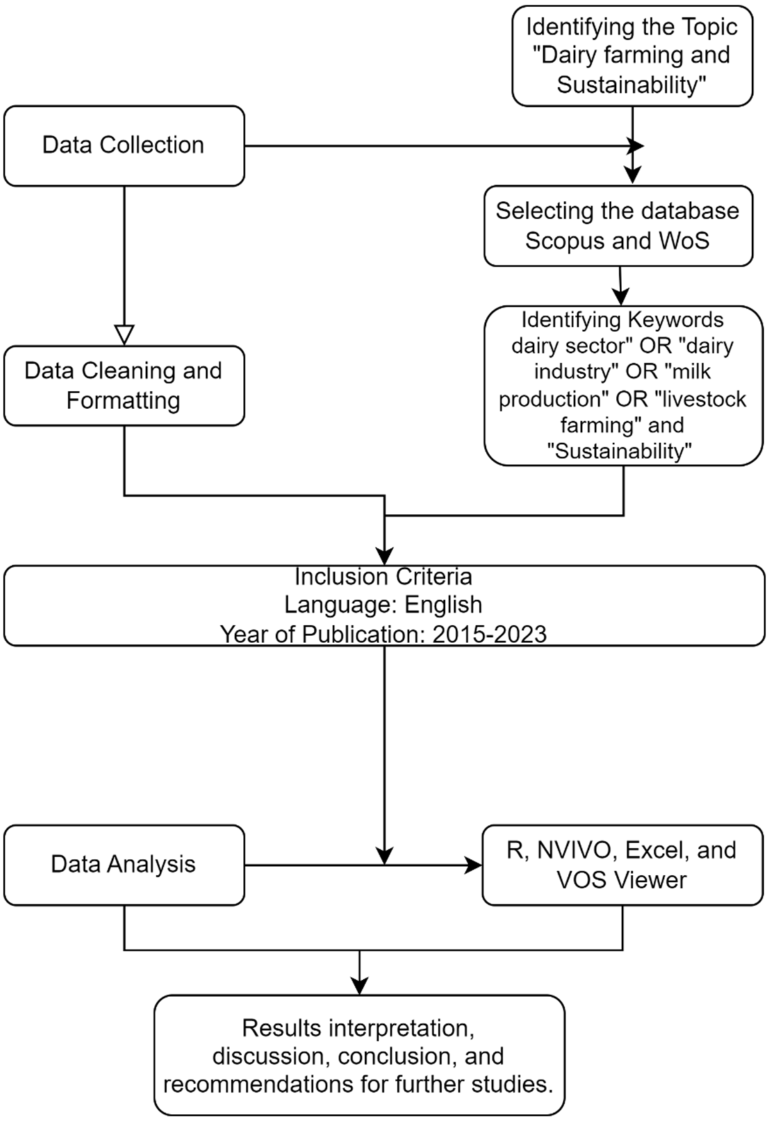


**Figure 1.** The Search Methodology.

The results obtained from the above search methodology is shown in the Table 1. These search results are from SCOPUS and the Web of Science (WoS).

**Table 1.** The Search Results.

| | | |
|---|---|---|
| Terms that have been searched are "dairy sector" OR "dairy industry" OR "milk production" OR "livestock farming" AND "sustainability" OR "sustainable development goals" OR "SDGs" | | |
| | Scopus | WoS |
| Article | 134 | 243 |
| Conference | 19 | 7 |
| Paper Review | 28 | 6 |
| Book Chapter | 14 | 6 |
| Book | 1 | 2 |
| **Limit to document type, relevant area** | | |

| | | |
|---|---|---|
| Articles | 134 | 243 |
| Total | 377 | |
| Cumulative total | 102 | |
| Duplicates | 275 | |
| Remaining | 0 | |
| Abstract Review | 275 | |
| Articles reviewed | | |

The third section shows the research findings based on the three research questions. Each question will be addressed independently.

## 3. Results

The research findings are divided into three parts based on the research questions. The first section shows the publication trends, the second section- the most prolific scholars, articles, Journals, and countries contributing to dairy farming and sustainable development, and third section- the research themes from the literature review and areas for future research.

### *3.1. The Publication Trends*

This section explores the publication trends in dairy farming and sustainability from 2015. It shows the annual number of publications from 2015 to 2023, Article's annual growth, and the price law. Each of these measures is explained independently.

**Annual Number of Publications from 2015 to 2023.**

The study examined the number of scientific publications published from 2015 to 2023 to identify the trends and the results are shown in Figure 2.

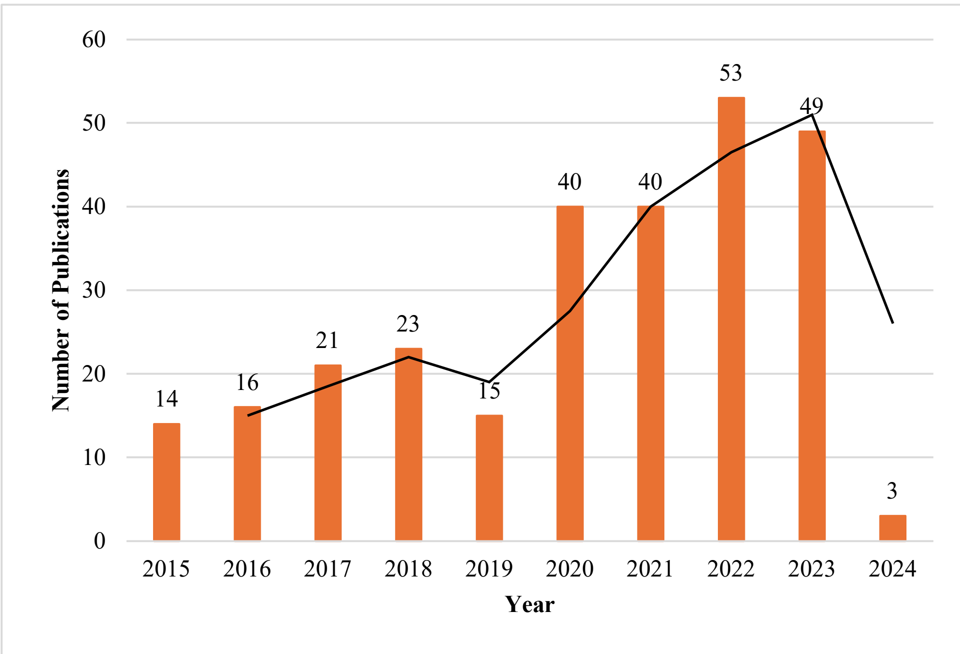


**Figure 2.** Annual Publications.

Researchers interest has been drawn to the field as illustrated in Figure 2, which shows a constant increase in publications on dairy farming and sustainability from 2015. Nonetheless, there was a decline in 2019, followed by more than duo-fold increase in proceeding years. In 2023, there was a slight decline in publications compared to 2022. This trend is further supported by the price law, which is illustrated in Figure 3.

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**Price Law**

Price law shows productivity distribution in a scientific discipline. It states that only few scholars make a significant contribution and discoveries in a particular discipline. This law helps to identify key contributors in a research area and productivity over time. We run an exponential growth curve to estimate productivity over time and the results are shown in Figure 3. The results show an exponential growth value 0.1741 over time. The model has a strong goodness of fit, explaining 84% of data variability. These findings support the prior high productivity assertion. The reap in scientific research in dairy farming and sustainability can be explained by the adoption of sustainable goals in 2015. Since then, countries have formulated sustainability-based policies that govern their economic operations and production.

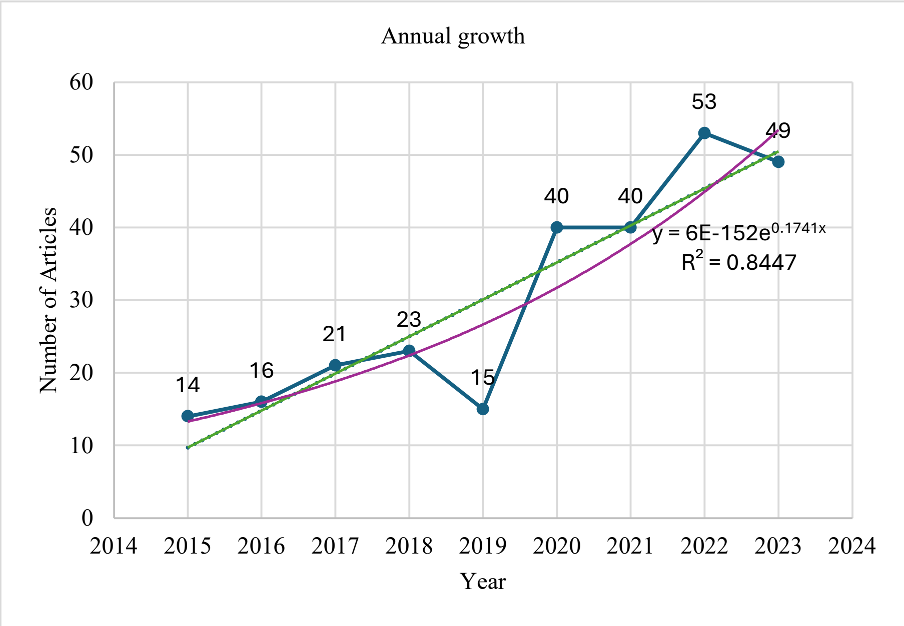


**Figure 3.** Article's Annual growth over Time.

*3.2. Prolific Sources, Articles, and Authors.*

This section shows the most relevant sources, most cited journals, the source impact, most cited articles, prolific scholars, and country's production over time.

**Most Relevant Sources**

The research examined the most relevant sources in dairy farming and sustainability and the results are shown in Figure 4 shows the top ten journals**.**

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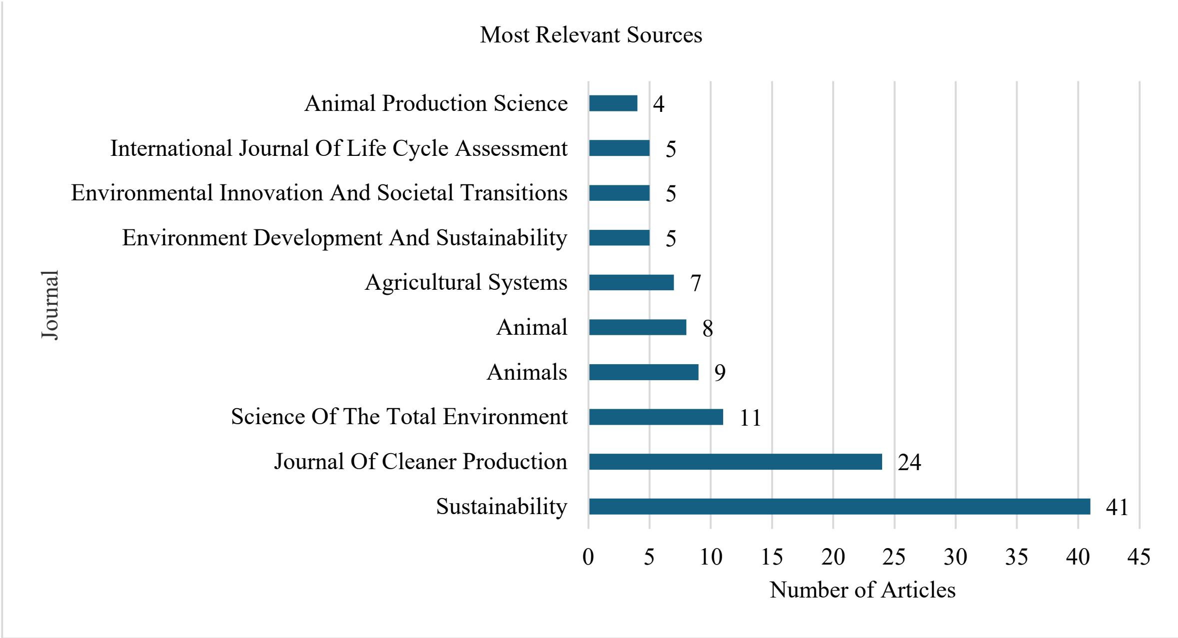


**Figure 4.** Top Ten Most Relevant Journals.

The Sustainability journal has the most articles, 41, followed by the Journal of Cleaner Production,24, and the Science of the Total Environment Journal (11 articles). Most Journals had five publications. The Animal Production Science has the least publications (4). Most of the journals-4, are in the agricultural field since dairy farming is majorly covered in agriculture. Nonetheless, environment, sustainability, and production journals have also explored the field. This implies that sustainable dairy production is a multidiscipline area that has drawn attention from scholars in diverse areas.

**Most Cited Journals**

The study further examined the local citations of the top ten listed journals to identify the journal with the most citations. The results are shown in the Figure 5.

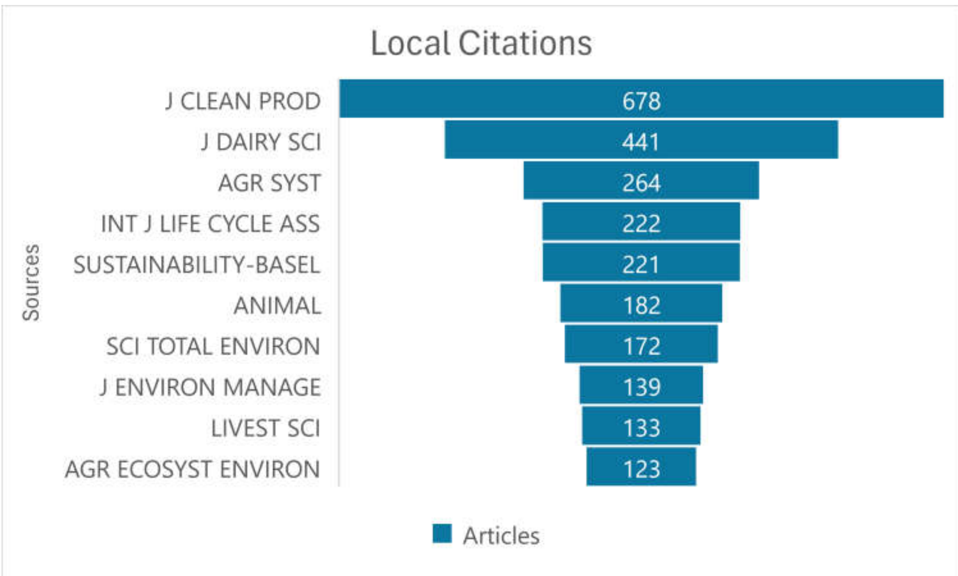


**Figure 5.** Most Cited Journals.

The Journal of clean production has the highest local citations, 78, followed by the Journal of dairy science, 441, and Agriculture Systems (264). The Journals had at least 123 citations. The Journal of Agriculture Ecosystem and Environment had the least citations. Multiple journals, such as

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Sustainability, Animals, and Animal Production had the most articles as shown in the previous analysis, but do not appear among the top ten ranking. This implies that the most cited journals may have fewer, but highly cited articles in dairy farming and sustainability.

**The Sources Impact.**

Further, the study examined the journals H-index to determine their impact. H-Index measures a researcher's scientific output and Hirsch (2005), explained that "A scientist has index H if H of his or her Np papers have at least H citations each and the other (Np-h) papers have less or equal H citations each". This index is highly preferred because it combines impact and quantity and measures scientific output objectively. The results show that the top ten sources had a least H-index of 3 and utmost 14. The Journal of Cleaner Production had the highest H-index (14), while Animal Production Science has the least (3). Most Journals had an Index of 5. Journals with high citation score have a high H-index and most of the journals in the top citation list have a high H-index. This implies that journals on sustainability have a higher ranking due to increased research interest in sustainability.

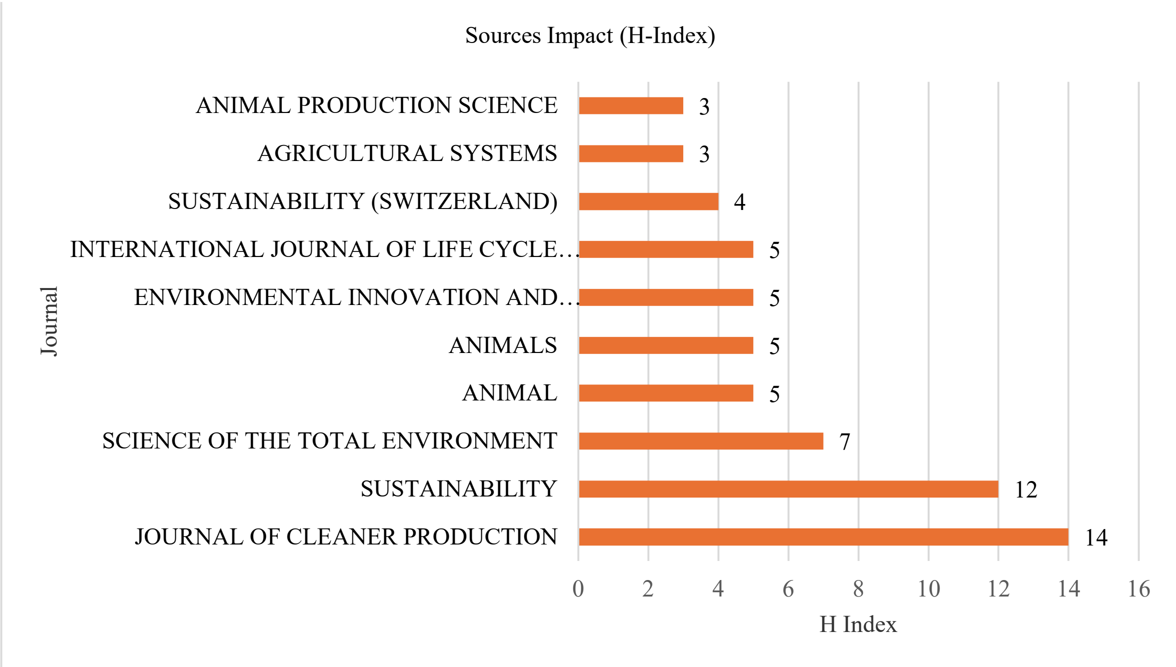


**Figure 6.** Sources Impact (H-Index).

**Most Cited articles**

The Study further explored the top ten most cited articles to identify influential studies, explore research trend, and measure the research impact. Figure 7 shows the topmost cited articles globally in dairy farming and sustainability.

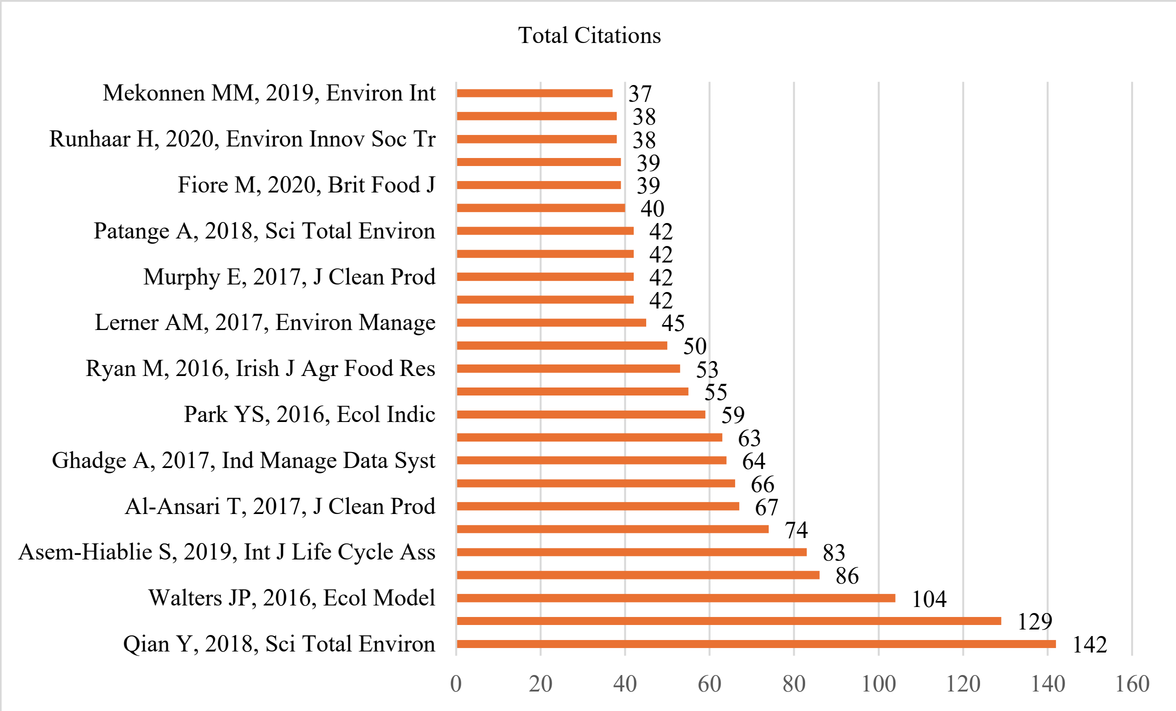


**Figure 7.** Most Cited Articles.

Qian (2018) is the most cited article, with 142 citations, followed by Walters (2016), 129, and Asem (2019), with 104 citations. The least cited article in the list has 37 citations. Nonetheless, articles with most citations were published earlier compared to others. Nonetheless, there are multiple latest publications with higher citations. For instance, Asem (2019) is more cited than Murphy (2017) and Park (2016). Therefore, though articles published earlier have a citation upper hand, a recent published study with strong relevance can attract more citations as well.

**Journals Listing and Articles distribution Based on Bradford Law**

Bradford law is a widely used bibliometric law that examines the output of scientific journals. The law states that ""if scientific journals are arranged in order of decreasing productivity of articles on a given subject, they may be divided into a nucleus of periodicals more particularly devoted to the subject and several groups or zones containing the same number of articles as the nucleus". Table 2 shows a summary of journal listing and articles distribution based on the Bradford Law.

**Table 2.** Summary of Journal Listing and Articles Distribution.

| **Bradford Law** | | | | | |
|---|---|---|---|---|---|
| **Journals** | | | **Articles** | | |
| | N | % | | N | % |
| Zone 1 | 5 | 4% | Zone 1 | 93 | 34% |
| Zone 2 | 33 | 26% | Zone 2 | 91 | 33% |
| Zone 3 | 90 | 70% | Zone 3 | 90 | 33% |
| | 128 | | | 274 | |

The results show that zone 1 had a minimum of five journals which increased sixfold in zone 2. Besides, articles in zone 2 increase threefold in zone 3. On the other hand, articles are uniformly distributed in the three zones. Each zone has about 92 articles (33%). The results align with Bradford's law, which requires articles to be uniformly distributed across the zones and few journals to contain most articles.

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**Prolific Scholars**

The study examined the most prolific scholar based on the H-index. Similar to journal impact, H-index is used to measure the impact of the scholars in a given field. Figure 8 shows the top ten scholars in dairy farming and sustainability.


**Figure 8.** Author's Impact (H-index).

Arsenos G. and Del P. are the most prolific scholar with 5 publications authored individually or co-authored with other scholars. Franca A., Lee M., Pardo G., and Vagnoni E. are the second most prolific scholars in dairy farming and sustainability since 2015 with 4 publications authored individually or co-authored with other scholars. Buckley C., Dillon E., Duce P., and Hennessy T., have 3 individual or coauthored publications.

**Country Production over time**

The study examined the top ten countries with the most articles to identify the country leading in studies related to dairy farming and sustainability. The findings are shown in Figure 9.

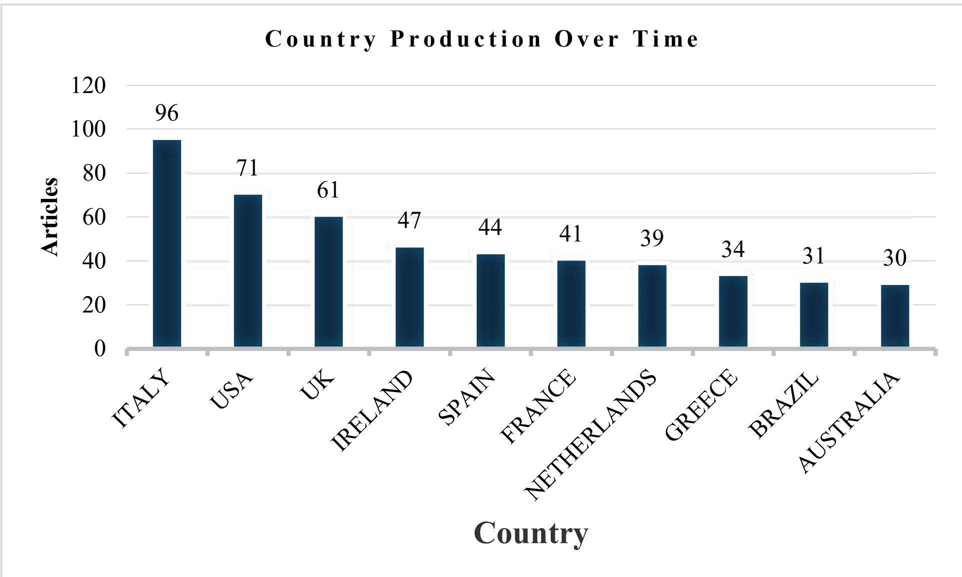


**Figure 9.** Country Production over Time.

The results show that Italy is leading with 96 publications followed by USA (71), United Kingdom (61), Ireland (47), Spain (44), France (41), Netherlands (39), Greece (34), Brazil (31), and Australia (30). Italy and Australia are the leading milk producers in the world, which can be

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attributed to their interest in researching sustainable practices in dairy farming. It is worth noting that no Asian or African Country is featured among the top ten.

**Lotka's Law**

Lotka's law is used to evaluate the productivity of authors. The law states that "The number of authors making n contributions is $1/n^2$ of those making one, and the proportion of contributors making a single contribution is 60%." Table 3 shows the productivity of authors based on Lotka's law.

**Table 3.** Author's Productivity.

| Documents written | N. of Authors | Proportion of Authors |
|---|---|---|
| 1 | 1025 | 0.872 |
| 2 | 123 | 0.105 |
| 3 | 18 | 0.015 |
| 4 | 6 | 0.005 |
| 5 | 4 | 0.003 |

The results show that 87% of the researchers in dairy farming and sustainability had published 1 article, 10%; 2 articles, and 1.5%; 3 articles. The results do not align with Lotka's law assumption, which requires 60% of the authors to have a single publication.

**Co-occurence of Keywords**

We examined the co-occurrence of keywords to identify research trends, map knowledge domains, detect research front, and explore interdisciplinary connections on dairy farming and sustainability, Figure below shows the key words related to the study.

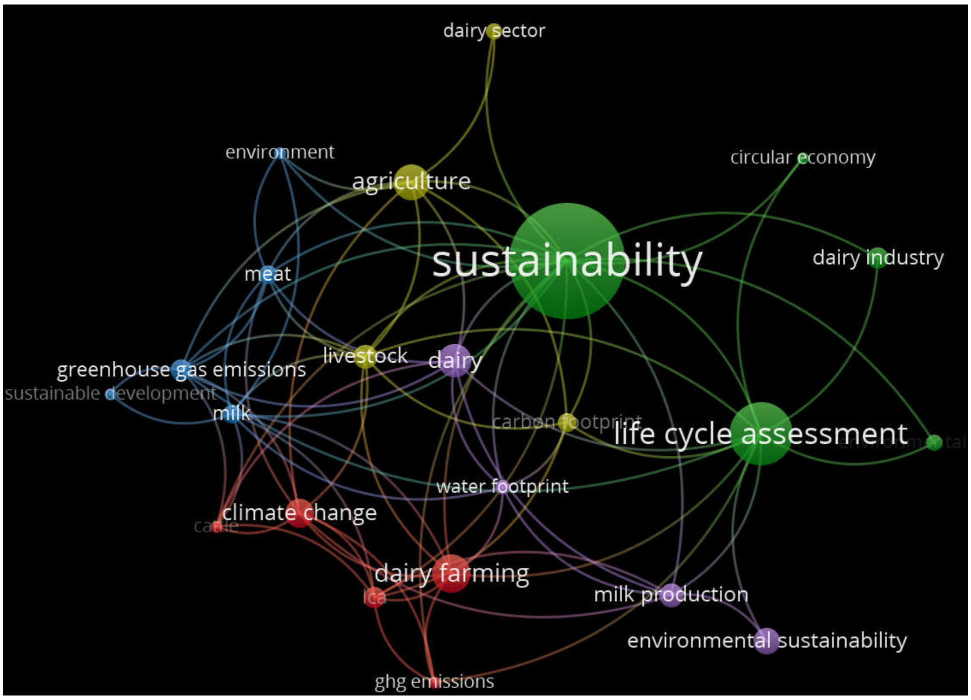


**Figure 10.** Co-occurrence of Keywords.

According to the output, cluster 1 contains sustainability as the key word, followed by life cycle assessment. Others in different clusters are dairy farming, climate change, environmental sustainability, agriculture, greenhouse emissions, milk production, circular economy, and water footprint. The co-occurrence of lifecycle assessment and sustainability emphasizes the examination of the environmental impact of dairy farming practices across the entire lifecycle of dairy products, production to consumption. It implies that researchers are examining approaches to make dairy farming operations sustainable by optimizing the use of limited resources and reducing environmental footprints. The occurrence of dairy farming in multiple clusters indicates its centrality to the overall research landscape as researchers examine various dairy farming aspects such as production approaches, economic viability, and animal welfare.

### *3.3. Literature Review of the Top Twenty Most Cited Articles*

The research reviewed the top ten articles with the greatest impact to identify themes, trends, and opportunities for future research. The table below shows the literature review of the top twenty studies.

**Table 4.** Literature review of the Top Twenty most Cited Articles.

| **Authors, Year, and Journal** | **Title of the Paper** | **Total Citations** | **Contribution to Dairy Sector and Sustainability** |
|---|---|---|---|
| Qian Y, 2018, | Environmental status of livestock and poultry sectors in China under current transformation stage [13]. | 142 | The paper provides policy recommendations for sustainable practices, including regulatory control, proper manure treatment, and financial incentives to promote ecological agriculture in China. Overall, the research underscores the need for sustainable livestock and poultry production. |
| Uwizeye A, 2020 | Nitrogen emissions along global livestock supply chains [14]. | 129 | The article suggests targeted interventions to reduce N pollution, such as improved fertilizer policies and integrated livestock-feed production. Global initiatives are needed to address N emissions while ensuring food security. |
| Walters JP, 2016 | Exploring agricultural production systems and their fundamental components with system dynamics modelling [15]. | 104 | The researchers evaluate three distinct production systems: crops only, livestock only, and an integrated crops and livestock system. They analyze the role of each driver in determining sustainability differences among these systems. The greatest potential for sustainability exists in the crops-only production system. |
| Ritchie H, 2018. | The impact of global dietary guidelines on climate change [16]. | 86 | Dairy intake is responsible for variations in emissions. Effective decarbonization requires not only a shift in dietary preferences but also a reevaluation of the recommendations supporting this transition. Improvements in feed production and use present significant opportunities for reducing environmental impacts. |
| Asem-Hiablie S, 2019 | A life cycle assessment of the environmental impacts of a beef and | 83 | The study examines the environmental impact of livestock keeping. According to the research, identifying areas for improvement in feed production and use, such as increasing crop and pasture yields, could be key to reducing |

| | | | |
|---|---|---|---|
| | dairy system in the USA [17] | | environmental impacts. The cattle production phase (Feed and cow-calf phase), including feed production, cow-calf, and finishing, has the most influence on most environmental categories. |
| Mangla SK, 2019. | Logistics and distribution challenges to managing operations for corporate sustainability: Study on leading Indian diary organizations [18]. | 74 | The research highlights the environmental impact of the dairy industry, including high greenhouse gas emissions and food wastage. It suggests that addressing cold chain management is crucial for reducing wastage, financial losses, and environmental issues. It suggests that addressing cold chain management is crucial for reducing wastage, financial losses, and environmental issues. |
| Al-Ansari T, 2017. | Integration of greenhouse gas control technologies within the energy, water, and food nexus to enhance the environmental performance of food production systems [19]. | 67 | The paper introduces a system that recycles solid waste from the dairy sector into useful energy, specifically mentioning dairy manure as a feedstock for the gasification process. Integrating carbon capture technology with BIGCC, transforming it into a negative greenhouse gas emission technology, which could result in a near carbon-neutral food system. |
| Richter BD, 2020. | Water scarcity and fish imperilment driven by beef production [20]. | 66 | The research explores water scarcity and fish imperilment in cattle farming. According to the findings, irrigation of Cattle-Feed Crops and beef and dairy consumption is the largest consumer of river water in the western United States, significantly impacting water scarcity and causing ecological imbalance. The study suggests reducing cattle-feed crops and rotational fallowing can enhance ecological sustainability. |
| Ghadge A, 2017. | Implementing environmental practices within the Greek dairy supply chain: Drivers and barriers for SMEs [21]. | 64 | The study established that internal as well as external drivers influence the implementation of sustainable practices in the FSC. However, the internal drivers carry higher weightage in the drive toward sustainability. |

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| | | | |
|---|---|---|---|
| Chen WH, 2017. | Social life cycle assessment of average Irish dairy farm [22]. | 63 | The study noted that Irish dairy farming has positive social impacts on value chain actors and society, predominantly positive impacts for local community and generally positive values for workers. Improving manure storage, introducing better handling methods, and using real-time decision support to operational management, and robots have the potential to reduce emissions that caused adverse "health and safe living condition" impacts for the local community. |
| Park YS, 2016. | Energy and end-point impact assessment of agricultural and food production in the United States: A supply chain-linked Ecologically based Life Cycle Assessment [23]. | 59 | Grain farming, dairy food, and animal production-related sectors were found to have the greatest shares in both environmental and ecological impact categories as well as endpoint impact. Integrating biological and ecological concepts into Agri-food production will minimize the use of nonrenewable resources. reduction of food waste, improve efficiency of operation and process, use of proper solar energy in the Agri-food sector and converting intensive agriculture into organic farming can enhance sustainability. |
| Ghadge A, 2021. | Sustainability implementation challenges in food supply chains: a case of UK artisan cheese producers [24]. | 55 | The analysis identified several key barriers, including initial investment cost, firm size, and unawareness of government regulations. The internal barriers significantly dominate the implementation of sustainability practices in comparison to external barriers. Lack of consensus regarding the concept of sustainability by different stakeholders is observed to be an issue negatively affecting the level of integration in SMEs. |
| Ryan M, 2016. | Developing farm-level sustainability indicators for Ireland using the Teagasc National Farm Survey [25]. | 53 | The analysis undertaken in this study shows that dairy farms, followed by tillage farms, tend to be the most economically sustainable of the four farm systems examined. intensive dairy systems produce more GHGs than other less-intensive systems, the consistent pattern across all farm systems is the positive correlation between economic performance and environmental sustainability, driven by higher output and more efficient use of inputs. increases in efficiency and productivity generate increased profits, without increasing negative environmental consequences |

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| Lerner AM, 2017, | Sustainable Cattle Ranching in Practice: Moving from Theory to Planning in Colombia's Livestock Sector [26]. | 45 | The article reviews the concepts and discussion associated with reconciling cattle production and conservation. Disaggregating the cattle sector regionally and by production type, defining the most important areas for conservation, and understanding geographical biophysical limitations and opportunities for production strategies. It also requires coordinating across government sectors, including environmental sectors, agricultural sectors, and education and capacity-building sectors. The efforts to encourage more sustainable cattle production strategies can be linked to international financial mechanisms and to national goals for restoration and carbon mitigation. |
| Vermunt DA, 2020. | Sustainability transitions in the agri-food sector: How ecology affects transition dynamics [27]. | 42 | Agency-Incentivizing change among farmers can enhance biodiversity-friendly practices. Novelty-Institutional change consisted of new socio-institutional frameworks and incentives for farmers to change agricultural practices, often in the form of business models. Upscaling models for change cannot easily be scaled, replicated, or standardized. |
| Murphy E, 2017. | Water footprinting of dairy farming in Ireland [28]. | 42 | The objective of this study was to determine the primary contributors to freshwater consumption in Irish dairy farms. The utilization of green water available at a low opportunity cost compared to blue water to produce milk demonstrates the sustainability of milk production in Ireland with respect to water consumption. |
| Hjalsted AW, 2021. | Sharing the safe operating space: Exploring ethical allocation principles to operationalize the planetary boundaries and assess absolute sustainability at individual and industrial sector levels [29]. | 42 | The study provides a demonstration of the feasibility of the method by implementing the framework to two of the planetary boundaries (climate change and biogeochemical flows) for the dairy sectors in India, Denmark, and globally. A two-step process is proposed, first downscaling to the individual level using ethically founded allocation principles and then upscaling to any higher level than the individual (such as product, industry sector, or nation) through separate upscaling methods. This allows stakeholders to transparently assess their absolute sustainability status. |

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| Patange A, 2018, | Assessment of the disinfection capacity and eco-toxicological impact of atmospheric cold plasma for treatment of food industry effluents [30]. | 42 | This study also investigated the eco-toxicological impact of cold plasma treatment of the effluents using a range of aquatic bioassays. Continuous ACP treatment was applied to synthetic dairy and meat effluents. The study showed proof-of-principle on safe treatment of food sector wastewater effluents using ACP for decontamination, with useful efficacy within short periods of both treatment and retention times. ACP treatment was shown as a promising technology for reduction and complete inactivation of key indicator microorganisms in model dairy and meat wastewater effluent. |
| Cole AJ, 2015. | Bio recovery of nutrient waste as protein in freshwater macroalgae [31]. | 40 | The aims of this study were to investigate the relationship between nitrogen supply, biomass productivity and the quantity and quality of protein in the freshwater macroalga, Oedogonium. Integrating the production of Oedogonium into the waste management of intensive animal production will provide a mechanism to recover nutrients which, firstly, delivers a novel source of protein for the agricultural sector and, secondly, contributes to the environmental sustainability of intensive animal production through bioremediation |
| Fiore M, 2020, | Stakeholders' involvement in establishing sustainable business models: The case of Polish dairy cooperatives [32]. | 39 | The aim of the study is to define a sustainable business model of dairy cooperatives and explore how stakeholders can contribute to innovation processes generated in this ecosystem. The findings of this paper show how the involvement of various stakeholders by the cooperatives contributes to the development of innovations that meet customer expectations, thereby concurring to the creation of social, environmental, and economic value. The opportunity to adopt a SBM is the result of a continuous interaction with various stakeholders who contribute to varying degrees to the sustainability of the processes and the value co-creation |

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| Makkar HPS, 2016 | Smart livestock feeding strategies for harvesting triple gain–the desired outcomes in planet, people, and profit dimensions: a developing country perspective [33]. | 39 | The analysis and synthesis presented reveal that the efficient utilization of feed resources and application of appropriate feeding strategies is vital for sustainability of the livestock sector. identifies and explores a series of promising innovations and practices in feed production and feeding including balanced and phased feeding; increase in the quality and level of use of forages in diets; reduction in use of grains; harvesting forages when nutrient availability per unit of land is maximum; targeted mineral feeding; reduction in feed losses; use of straw-based densified feed blocks; better recycling of human food wastes and human-inedible food components to feed; new business models for production and use of urea-ammoniated straws, urea-molasses blocks, forages and silages in smallholder farms; and use of underutilized locally available feed crops linked with strengthening of seed development and distribution infrastructure |

A review of the literature on the top 20 articles in sustainability of dairy sector helps to identify the thematic issues associated with dairy farming and areas of further research. This section explores each theme and provides opportunities for further research.

### *3.4. Thematic Analysis*

This section explores themes identified from the literature review namely, Livestock management, feed production and management, innovation, stakeholders' involvement, logistics and supply chain management, and waste management.

**Theme 1. Livestock Management**

The reviewed literature shows that the evolving landscape of environmental sustainability within the dairy sector is intricately tied to the management of livestock. Intensive dairy systems, while capable of high output, increase the amount of greenhouse gases emitted in the sector, thereby impairing conservation measures, and posing a significant challenge to the overall sustainability efforts. Consequently, this observation necessitates a revaluation of current practices in favor of more sustainable approaches. In this regard, study results imply that rotational fallowing is a strong and ideal solution as it allows land rejuvenation and soil health to flourish thus enhancing ecological sustainability. Moreover, the literature supports the pivotal role of cattle production phase, spanning from feed production to cow-calf rearing and finishing, in sustainability. This phase cuts across multiple environmental categories, which signifies the benefits of targeted conservation interventions within livestock management. Therefore, environmental sustainability in the dairy sector requires a comprehensive approach that prioritizes innovative strategies for livestock management, optimizing the cattle production phase and integrating rotational fallowing techniques can not only mitigate greenhouse gas emission, but also foster ecological resilience.

**Theme 2. Feed production and Management.**

Feed production and management within the dairy sector contains complexities that should be addressed in the pursuit of environmental sustainability. The key and notable challenge is shift in dietary preferences, which requires re-examining feed production to meet ever changing consumer demands. This shift poses a dual challenge, minimizing environmental impact of food production

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while meeting the nutritional requirements of dairy livestock. Moreover, the animal feed supply chain is characterized by food wastage, thus creating resources inefficiencies, and adding to environmental degradation. Literature shows that irrigating cattle feed crops often results in water wastage, which presents a substantial concern for sustainable water management.

Besides irrigation, dairy food production approaches require prompt optimization to mitigate ecological impact as it carries a substantial environmental footprint. Reliance on grains in formulating feeds is associated with intensive agricultural practices that amplify environmental degradation and resource depletion. Additionally, poor feeding strategies and inept utilization of feed resources further aggravate environmental strain, demanding a shift towards more sustainable practices.

To address these complex challenges in the feed production and management value chain, it is crucial to adopt multifaceted approaches that promote environmental sustainability within the dairy sector. One key solution is adopting a market driven transition to more sustainable feed production and management approaches that realign feed production and usage with shifting dietary preferences and sustainable development goals. Concurrently, systematic interventions should be implemented in each stage. For instance, resources should be optimized, and efficiency emphasized to address food wastage.

Secondly, optimizing feed production, embracing sustainable alternatives (green water irrigation), and developing new innovations in water management approaches and irrigation techniques can enhance resources efficiency, address water wastage, and reduce environmental footprint of feed production. Thirdly, strategic interventions, focusing on reducing reliance on grains in feed formulations and improving harvesting practices to enhance forage quality and quantity are vital approaches towards sustainability. Besides, feeding systems that are balanced and phased alongside innovative feed formulations and targeted mineral supplements are essential.

Thirdly, it's central to align improved productivity with environmental imperatives. Ecologically sound practices increase crops and pasture yields while conserving the environment. Finally, the literature underscores the importance of transitioning from intensive agriculture to organic farming. This transformative approach integrates ecological and biological principles into agricultural food production. Stakeholders can navigate the animal feed production complexities and foster a resilient and environmentally conscious industry by embracing these comprehensive solutions.

**Theme 3. Innovation**

Innovation emerges as a central theme in the dairy sector that enhances environmental sustainability in the analyzed literature. It provides numerous transformative solutions that are poised to reshape the industry practices in the quest to enhance sustainability. Foremost, the use of robots can help to optimize dairy farming operations. They revolutionize efficiency while minimizing resource inputs and aligning with sustainability objectives. For instance, automated milking systems and precision livestock management. Additionally, harnessing proper solar energy and reducing reliance on fossil fuels are sustainable energy solutions in the sector that can mitigate greenhouse gas emissions associated with traditional energy sources.

Moreover, innovative socio-institutional frameworks and incentives foster the adoption of sustainable agricultural practices among dairy farmers as they support and provide incentives for environmentally friendly approaches. These frameworks catalyze a shift towards more sustainable production methods, for instance downscaling ethical allocation principles to the individual level further reinforces this transition and empowers farmers to make informed decisions that prioritize sustainability within their operations.

Developing consumer-centric innovations also holds promise in driving demand for sustainable dairy products. Innovations, such as eco-friendly packaging and traceability technologies, encourage consumers to make environmentally conscious choices and help to incentivize sustainable practices throughout the dairy supply chain.

Innovative feed production and feeding practices are central promoters of sustainability within the dairy sectors as they optimize feed formulations, reduce waste, and incorporate alternative feed

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sources. These practices enhance resource efficiency and minimize environmental impact associated with feed production.

Conclusively, it is evident that innovation is a catalyst for achieving sustainability within dairy farming as it revolutionizes operational practices, promotes renewable energy sources, fosters institutional support, empowers consumers, and optimizes feed production. Embracing these innovative solutions can help stakeholders to navigate the complexities of dairy farming while simultaneously advancing environmental sustainability goals.

**Theme 4. Stakeholders Involvement**

Stakeholders is the fourth theme present in the reviewed literature. It is evident that stakeholders play a central role in driving and pushing sustainability initiatives in the dairy sector. However, the research highlights numerous stakeholder engagement challenges and opportunities that directly affect dairy sector's ability to attain sustainability goals.

Lack of consensus among stakeholders is a significant impediment to attaining sustainable development goals in the dairy sector identified in the literature. The disagreement stems from divergent interests, conflicting priorities, and limited communication channels between stakeholders within the dairy value chain. To address this challenge, fostering coordination between key players and government sectors, such as environmental, agricultural, and education is imperative to facilitate knowledge sharing, policy alignment, and capacity-building initiatives. Establishing common goals and promoting cross-sectoral dialogue enable stakeholders to work together more effectively to overcome challenges and drive sustainable practices within the dairy sector.

Besides, cooperatives that bring together stakeholders are a catalyst for innovation in dairy farming. For instance, collaborative efforts between farmers, researchers, policymakers, and other stakeholders can spur the development and adoption of innovative practices and technologies as it helps to leverage on collective expertise and resources, which facilitate knowledge transfer, experimentation, and scaling of sustainable solutions. This inclusive approach or cooperation between key players empowers stakeholders to co-create initiatives that address the sector's unique challenges while advancing sustainability objectives.

The opportunity to adopt a Strategic Business Model (SBM) as supported in the literature can facilitate continuous interaction with various stakeholders. Engaging with stakeholders allows dairy farmers and industry players to gain valuable insights, identify emerging trends, and anticipate future challenges. Besides, actively involving stakeholders in strategic decision-making processes, such as developing business models and dairy farming enterprises, can help to align dairy farming operations with sustainability principles. This collaborative approach enhances effectiveness and long-term viability of the sector by fostering transparency, accountability, and shared ownership of sustainability initiatives.

In essence, engaging stakeholders drives sustainability efforts within the dairy sector. Consequently, addressing challenges such as lack of consensus, fostering collaboration, and leveraging diverse expertise, stakeholders can collectively foster sustainability in the industry. Dairy farming stakeholders can unlock innovation, resilience, and growth opportunities by adopting coordinated action and inclusive decision-making, which are essential to safeguard the environment and support local communities.

**Theme 5. Logistics and Supply Chain Management.**

Logistics and supply chain management is an additional theme identified in the reviewed literature that plays a critical role in both operational efficiency and environmental sustainability. However, innovative solutions are required to mitigate inherent challenges such as high greenhouse gas emissions and food wastage associated with logistics and transport.

Greenhouse gas emissions and food wastage from logistics and transport within the dairy sector are common. They stem from transportation of dairy products, feed, and other inputs that often involve extensive use of fossil fuels and food spoilage and wastage during transportation. Often, the dairy sector is characterized by inefficient transportation and poor storage that adversely affect the environment and lead to wastage of feeds.

To address these challenges, it is imperative to adopt solutions that seek to improve logistics and supply chain management in dairy farming. Implementing real-time decision support systems provides timely insights and data driven recommendations for logistics management that can enhance operational efficiency. The dairy sector can leverage on advanced analytics and technology to optimize transportation routes, minimize idle time, and reduce fuel consumption, thereby improving overall efficiency of resources and mitigating the emission of greenhouse gases. Furthermore, precision agriculture, automation, and data-driven decision-making can help farmers to achieve higher output and use inputs more efficiently by optimizing resource allocation, minimizing waste, and maximizing productivity. These approaches can help dairy farmers to reduce their environmental footprint while enhancing profitability and resilience of the sector. In addition, efficient management of the cold chain is essential for preserving the quality and safety of dairy products from farm to the consumer. Implementing proper storage, handling, and transportation practices, farmers in the dairy sector can minimize food wastage, reduce financial losses, and mitigate environmental impacts associated with spoilage and waste.

**Theme 6. Waste Management**

Waste management is another theme highlighted in the literature as critical within the dairy sector. Poor handling of waste can result in significant greenhouse gas emissions and environmental degradation. The most common wastes in dairy farming are solid waste and wastewater effluents. They pose challenges that require innovative solutions to mitigate their impact on the environment.

Poor management of solid waste generated from dairy farming operations results in the release of greenhouse gases. To avert this, firstly, carbon capture technology should be integrated with Biomass Integrated Gasification Combined Cycle (BIGCC) systems to effectively neutralize the gases emitted by the solid waste. This system not only captures but also stores carbon dioxide emissions, thus mitigating their environmental impact while producing useful energy. Additionally, recycling solid waste from the dairy sector into bioenergy offers a sustainable alternative to conventional waste disposal methods, which reduces both waste accumulation and constant reliance on fossil fuels.

Methane gas emitted from the dairy farming sector can be addressed by improving manure storage and introducing better handling methods. The implementation of anaerobic digestion systems or composting techniques can help farmers to efficiently manage manure while capturing methane for energy production. In addition to improving manure storage and handling approaches, waste water can be safely decontaminated using Advanced Oxidation Processes (ACP), which mitigate pollution of water bodies, thus safeguarding the environment and human health.

There are innovative biological approaches highlighted in multiple studies that can help to manage waste and enhance sustainability in the sector. Integrating algae, such as the production of Oedogonium, into waste management practices of intensive animal production presents an innovative approach to nutrient recovery. Oedogonium utilizes nitrogen and phosphorous in the waste streams to grow biomass that can be used in biofuel production and animal feed supplementation. This closed-loop system reduces pollution and enhances resource efficiency within the dairy farming ecosystem.

Furthermore, better recycling of human food wastes and human-inedible food components into animal feed offers a sustainable solution to reduce waste and improve resource utilization as it diverts food waste from landfills and integrates it into the feed supply chain. Thus, effective waste management practices are crucial for promoting sustainability within the dairy farming sector and implementing innovative solutions such as carbon capture technology, waste recycling, and nutrient recovery systems, stakeholders can minimize greenhouse gas emissions, reduce pollution, and enhance resource efficiency, contributing to a more sustainable and resilient dairy farming industry.

## 4. Discussion, Conclusions, and Recommendations

The bibliometric analysis of sustainability in the dairy sector shows a rise in scholarly interest in dairy farming and sustainability as evidenced by increase in publications since the adoption of sustainable development goals in 2015. However, the variations in research activities over time, for instance a decline in 2019, followed by rapid growth in proceeding years, points to underlying dynamics that require further studies. The exponential growth curve analysis further underscores the robustness of research output due to the significant rise in productivity over time and aligns with the adoption of global sustainable goals in 2015. These findings are a clear indicator of global commitment to addressing current environmental challenges and promoting sustainable development in dairy farming. Further, the complexity of sustainability in the dairy sector and multidisciplinary nature of dairy production is shown by a wide range of journals contributing to the discourse. Notwithstanding the disparities in journal visibility and impact, the review of articles with high citation shows historical foundational research and current advances shaping dairy farming and sustainability research discourse. Nevertheless, there are numerous research gaps that require additional scientific exploration, for instance, there is a need to explore factors driving fluctuations in research activity since 2015, examine the impact of sustainability-based policies, and evaluate the temporal dynamics of citation patterns.

From thematic analysis, it is evident that the sustainability of dairy farming requires addressing complex challenges across the value chain. While dairy farming is integral to providing dairy products and food, the sector faces significant environmental concerns stemming from livestock management, feed production, waste management, stakeholders' involvement, innovation practices, and supply chain management. From the analysis, there is a need to shift towards sustainable livestock management practices, such as rotational grazing and optimized feed formulations since intensive dairy systems contribute substantially to greenhouse gas emissions. Moreover, there is a need to reduce food wastage and adopt efficient feed utilization approaches. Innovation emerges as a key driver of sustainability and source of opportunities to strengthen sustainability and achieve sustainable development goals. On the other hand, collaboration between stakeholders, such as farmers, policymakers, and consumers are essential for developing and implementing sustainable solutions. Logistics and supply chain management practices strongly influence the environmental impact and underscores the need to strengthen efficiency and adopt real-time decision support systems in the sector. It is imperative to recognize that management activities and operations that require human involvement in the dairy sector are key impediments to the sustainability of dairy farming and concerted efforts across the entire production and supply chain are needed.

**Conceptualization** DM and M.F.F; methodology DM and CB; software DM.; validation, DM, M.F.F and CB.; formal analysis, DM, investigation, DM.; resources, DM, M.F.F and CB.; data curation, DM.; writing—original draft preparation, DM.; writing—review and editing, DM.; visualization, DM.; supervision, M.F.F and CB.; project administration, M.F.F and CB.; funding acquisition, M.F.F. All authors have read and agreed to the published version of the manuscript.

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