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Unveiling Sustainable Leather: A Bibliometric Exploration of Eco-Friendly Future in South Asia

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Abstract

This study investigates the state of sustainable leather production in South Asia, with an emphasis on identifying key research trends, challenges, and opportunities for adopting eco-friendly practices within the region. The leather industry, a major economic driver in countries like India, Bangladesh, and Pakistan, faces environmental concerns due to its reliance on toxic chemicals and resource-intensive production methods. The primary objectives of this research are to analyze research trends in sustainable leather production, assess the adoption of circular economy principles, and identify technological innovations critical for a greener industry. A bibliometric approach is employed, analyzing academic literature from 2003 to 2024 to examine trends, influential authors, and emerging themes. The results highlight significant advancements in eco-friendly tanning agents and waste management but underscore challenges such as high costs, inadequate infrastructure, and fragmented supply chains. Moreover, the lack of comprehensive regulatory frameworks and low consumer awareness pose additional barriers to widespread adoption. This study contributes to the field by mapping the research landscape, identifying gaps, and offering recommendations for future studies in areas like economic feasibility, consumer behavior, and social sustainability. The findings provide valuable insights for policymakers, industry leaders, and researchers, suggesting a path forward through innovation, policy support, and enhanced collaboration to drive sustainable practices in South Asia's leather industry.

Keywords: Sustainable Leather Production, Circular Economy, Eco-friendly Tanning, South Asia, Bibliometric Analysis, Environmental Impact

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Introduction

The leather industry is fundamental to economic development in South Asia, especially in Bangladesh, India, and Pakistan. It is essential for job creation, foreign exchange revenue, and industrial development. Bangladesh's leather industry provides approximately 3% to the national GDP, employs over 850,000 individuals, and generates more than \$1 billion in yearly exports (Humayra et al., 2023), with a domestic market value of around \$2 billion (Khatun et al., 2024). In the fiscal year 2022-23, India's leather exports reached \$3.67 billion, positioning the country among the leading worldwide providers (Council for Leather Exports, 2023). Nonetheless, despite its economic importance, the leather industry continues

to be one of the most environmentally detrimental sectors in South Asia. It faces significant criticism for its environmental and social repercussions, chiefly attributable to its dependence on hazardous chemicals like chromium in tanning, excessive water usage, and inadequate waste management procedures (Dixit et al., 2015). The release of untreated effluents into aquatic systems results in significant contamination, endangering biodiversity and public health. It is estimated that more than 90% of tanneries in South Asia fail to adhere to appropriate waste treatment protocols, resulting in significant contamination of river ecosystems (Omoloso et al., 2021).

Due to the increasing global demand for sustainable and ethically sourced products, there is an imperative to shift towards ecologically friendly leather production techniques, including vegetable tanning, enzyme-based processing, and circular economy frameworks. The global leather market is transitioning towards sustainability, driven by environmentally aware consumers and international legislation that require cleaner production methods (Chishty & Sayari, 2024). The European Union has enacted rigorous environmental rules through the REACH Regulation, mandating leather exporters to implement sustainable practices (Sharma & Bhatt, 2020). Consequently, South Asian industries encounter heightened pressure to comply with sustainability criteria to maintain competitiveness in global markets.

Notwithstanding the increasing focus on sustainability, the implementation of eco-friendly methods in the South Asian leather industry is constrained by economic limitations, inadequate regulatory enforcement, and insufficient technological innovation (Iqbal et al., 2023). Numerous tanneries function in unregulated environments with constrained financial means to invest in cleaner technologies. The absence of appropriate incentives and insufficient policy frameworks have impeded the extensive adoption of sustainable practices (Kanagaraj et al., 2015). Although numerous studies have investigated sustainable leather manufacturing techniques and regulatory obstacles, a significant research deficit persists in the thorough evaluation of the academic landscape in this domain.

There is a deficiency of bibliometric evaluations assessing the progression of research themes, principal contributors, and collaboration networks in sustainable leather studies. A bibliometric evaluation can elucidate the most impactful works, developing trends, and knowledge deficiencies, thereby providing significant guidance for future research endeavors. The impact of digital transformation and developing green technologies on promoting sustainable leather production has not been thoroughly investigated (Omoloso et al., 2021). Technologies like blockchain for supply chain transparency, artificial intelligence (AI) for waste minimization, and bio-based tanning treatments are gaining prominence but require comprehensive research in the South Asian context.

A significant difficulty is the lack of a cohesive strategy that integrates environmental sustainability with social and economic considerations. The leather business employs numerous migrant and marginalized workers, many of whom endure perilous working conditions resulting from exposure to harmful chemicals and dangerous disposal methods (Kanagaraj et al., 2020). Sustainable development in the leather industry must integrate cleaner production methods, ethical labor practices, worker safety, and community welfare.

A bibliometric study of the current literature would facilitate the identification of gaps by offering a systematic assessment of advancements in sustainable leather research in South Asia. This study will examine research trends, identify seminal publications, and elucidate knowledge gaps to guide future research and policymaking. This study seeks to utilize bibliometric analysis to offer a framework for academics, industry professionals, and politicians to improve sustainability initiatives in the leather industry. A thorough

bibliometric analysis will elucidate the researchers' focus, identify collaborative hotspots, and highlight areas requiring further investigation.

The primary objectives of this study are to map the research trends in sustainable leather production in South Asia over the past decades, identify key themes and challenges addressed in existing research, analyze collaboration networks among authors, institutions, and countries, and highlight research gaps while proposing future research directions. By integrating these objectives at the conclusion of the introduction, the study establishes a clear roadmap that guides the bibliometric analysis, providing valuable insights for academics, industry professionals, and policymakers to foster sustainable practices in the leather sector.

Furthermore, comprehending the application of circular economy ideas in leather production is essential. The circular economy model prioritizes waste reduction, resource optimization, and material repurpose, which are very pertinent to the leather sector. Numerous nations are investing in biodegradable leather substitutes and waste-to-value methodologies, including the conversion of leather waste into gelatin and collagen for industrial uses (Karuppiah et al., 2021). Nevertheless, these improvements have not been extensively adopted in South Asia owing to elevated costs and technological obstacles.

This bibliometric analysis will substantially benefit academic and industry stakeholders by pinpointing the principal academic centers, top institutions, and prevailing research trends in sustainable leather manufacturing. Additionally, it will offer insights on enhancing research collaborations between South Asian nations and international leather research institutions. The results will be beneficial for legislators in formulating more effective sustainability rules, industry leaders in implementing cleaner and more profitable production methods, and researchers in tackling significant knowledge gaps.

The findings will enhance the global dialogue on sustainable industrial practices and aid in the establishment of ecologically responsible leather production systems. Considering the pressing nature of climate change and global environmental issues, South Asia must expedite its shift towards sustainability in the leather sector to secure enduring economic and ecological equilibrium. (Sharma & Bhatt, 2020).

Recent advancements in sustainable leather production highlight a transition towards innovative, eco-friendly materials such as fully plant-based and bio fabricated leathers developed by emerging companies, offering biodegradable alternatives with reduced environmental footprints (Alt. Leather, 2025; Melbourne Start-up, 2025). Concurrently, digital technologies including blockchain and artificial intelligence are increasingly adopted to enhance supply chain transparency and minimize waste (Fatorachian et al., 2025). Global regulatory pressures, notably stringent EU environmental frameworks, further compel leather producers—especially in South Asia—to adopt sustainable practices to maintain competitiveness (Hossain et al., 2025). Market forecasts predict robust growth for the eco-friendly leather sector, driven by evolving consumer preferences and innovations in plant- and mycelium-based substitutes with superior life cycle impacts compared to conventional leather (Wattanavichean et al., 2025; Market Insight, 2025; Comprehensive Review, 2025). These developments underscore the urgency of mapping current research trends, technological innovations, and challenges in sustainable leather production within South Asia, thereby informing policy, industry strategy, and future research agendas.

Methods and procedures

Bibliometric analysis is a widely utilized technique for identifying and monitoring developmental changes within a certain domain (Rahman et al., 2024). Systematic reviews and bibliometric research were conducted through a sequential sequence of steps (Rahman et al., 2024; Rahman et al., 2025), encompassing exploration, assessment, synthesis, and analysis (Saif et al., 2022). A set of criteria has been created and utilized to evaluate and select pertinent literature for the study (Dhamija & Bag, 2020).

Literature search

A systematic search methodology was utilized to locate peer-reviewed articles and records for this investigation. The reputable and extensively acknowledged research database, Scopus, was chosen for this purpose. Scopus, which encompasses a wide array of disciplines and emphasizes sustainability in leather production more than other databases, was selected as the preferred option (Sikandar et al., 2022; Ejsmont et al., 2020).

The authors have designated 2003 as the commencement and conclusion year for the literature review. All previously stated databases were analyzed to find pertinent research completed between 2003 to 2024, with the methodologies detailed in Table 1.

Table 1: Techniques and procedures for searching

Searching Keywords	Search within	Databases	Language	Period	Fundamental Query String	Total No. of Papers
Sustainable Leather Production in South Asia	Title, Abstract, Keywords	Scopus	English	2003-2024	TITLE-ABS-KEY (sustainable AND leather AND production AND south AND asia) AND PUBYEAR > 2003 AND PUBYEAR < 2024	532

Literature assessment process

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) flow diagram is a well-known and widely utilised framework for evaluating literature (O'Dea et al., 2021; Bastidas-Orrego et al., 2023). This paradigm provides a coherent and efficient approach for organizing literature for reporting objectives (Camilleri & Bresciani, 2022). Consequently, the figure-1 has been utilized in the present study.

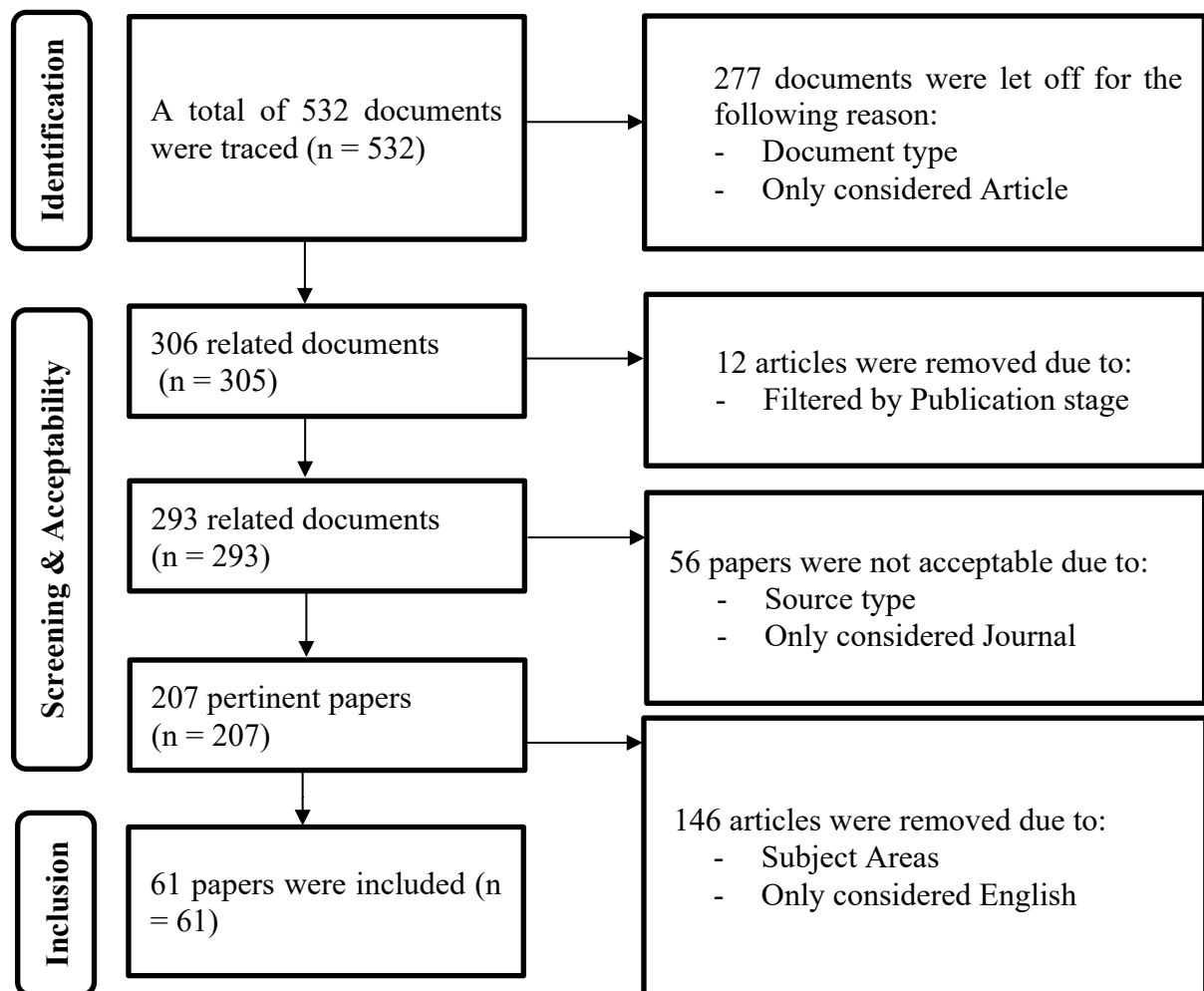


Figure 1: Updated PRISMA flowchart

Literature synthesis

Employing PRISMA, 61 texts were categorized and examined to extract bibliographic information, with the objective of identifying patterns and essential terminology. This stage is crucial for the bibliometric analysis to fulfill the study's objectives (Fiala & Maltseva, 2023). The bibliographic data were ultimately transformed into CSV and RIS forms (Saif et al., 2022) for subsequent analysis.

Analysis and reporting process

VOSviewer 1.6.18 is a widely used software for creating bibliometric maps and graphs (Abd Wahab, 2022). This study also utilises VOSviewer 1.6.18 to analyse the selected documents published between 2003 and 2024, with graphs illustrating the patterns and trends in publications.

Upon completing the analysis, 15 carefully selected papers are presented in table 2, and a thematic connection between crowdfunding and entrepreneurship is established using the cross-mapping technique.

Results and Discussion

Documents by Year

Figure 2 depicts the annual publication count of documents, highlighting the progression of research interest over time. The data indicates that between 2003 and 2015, the volume of publications was consistently low, with sporadic variations. From 2016 onwards, there is a significant escalation in research activities, particularly evident post-2019. The significant increase in document quantity in recent years reflects an intensified academic and industry emphasis on the research topic, particularly in reaction to developing global concerns and policy advancements.

The first decline in publishing rates (2003–2015) indicates a restricted academic emphasis, however the growth from 2016 onwards signifies heightened awareness of environmental issues. Policies such as the Bangladesh Leather Policy 2019, EU REACH rules, and the UN Sustainable Development Goals (Goal 12) have likely propelled this research expansion. The promotion of sustainable tanning, circular economy frameworks, and supply chain transparency has intensified scholarly attention.

Prior research, like Raihan & Melon Hossain (2021) and Shahid et al. (2023), corroborates this upward trajectory, emphasizing a transition towards sustainability-oriented inquiry. The increase after 2019 indicates enhanced collaborations between industry and academia, as well as global trade forces, like the EU Green Deal, impacting sustainable practices.

The rising volume of publications indicates the escalating significance of sustainable leather production. Future study must investigate technological advancements, regulatory adherence, and economic viability to promote sustainability within the sector.

Documents by year

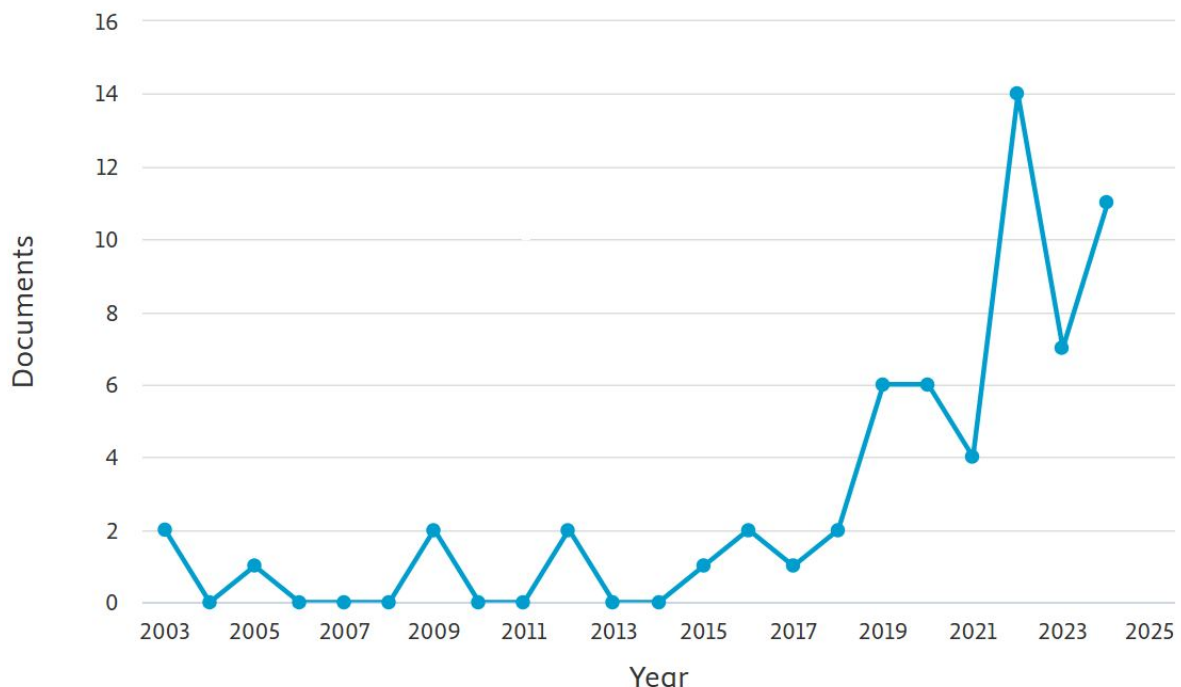


Figure 2: Document by year

Documents by Author

Figure 3 illustrates the leading authors in sustainable leather production research, demonstrating a balanced distribution of research output among them. The foremost three writers (Liu, X., Panda, R.C., and Wang, X.) emerge as the most prolific contributors in the research domain, signifying their substantial involvement in studies pertaining to sustainable leather manufacturing. The other authors have made significant contributions, but with fewer publications.

The existence of numerous authors with comparable document counts indicates a collaborative research setting, characterized by diversified contributions rather than concentration among a limited number of researchers. This tendency corresponds with international academic practices that prioritize multidisciplinary methods, co-authorship, and institutional partnerships to augment research impact. Research, like Sun et al. (2023) and Maghsoudi et al. (2023), underscores the significance of author networks in expediting innovation and knowledge diffusion within sustainability studies.

Furthermore, the authorship distribution indicates a growing scholarly interest in sustainable tanning methods, waste management, and circular economy practices within the leather sector. The participation of several researchers signifies a global emphasis, with contributions potentially encompassing numerous geographic areas.

This data highlights the cooperative and progressive aspects of sustainable leather research. Future study may investigate the institutional connections, geographical distribution, and topic contributions of these prominent writers to enhance comprehension of research trends in this domain.

Documents by author

Compare the document counts for up to 15 authors.

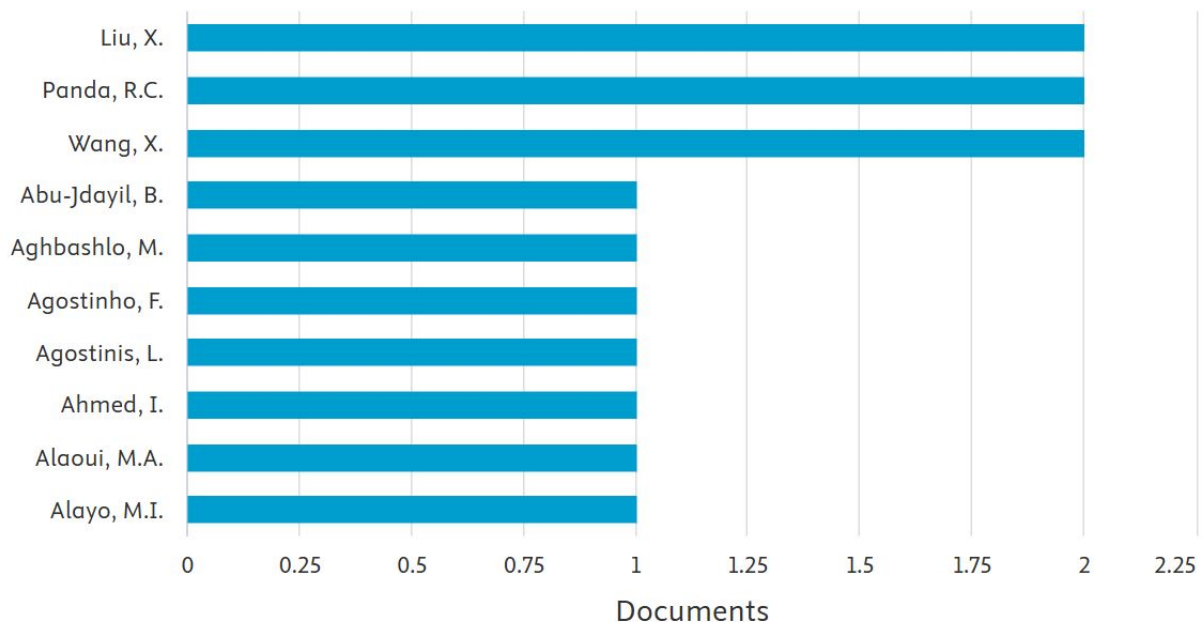


Figure 3: Documents by authors

Documents by Affiliation

Figure 4 illustrates the allocation of research contributions across various institutional affiliations, emphasizing the principal academic and research centers involved in sustainable leather manufacturing. Shaanxi University of Science and Technology ranks first among institutions in publication volume, succeeded by Università degli Studi di Firenze and Central Leather Research Institute, underscoring their pivotal contributions to research on sustainable leather processing, waste management, and circular economy methodologies.

Numerous additional universities and research institutions, such as Università degli Studi di Padova, University of Dhaka, Sichuan University, and Anna University, have made significant contributions, indicating a worldwide interest in sustainable leather production. The affiliation of the Ministry of Education of the People's Republic of China indicates official engagement in advancing sustainability research, consistent with regulations that promote environmental accountability in industrial activities.

Current literature indicates that institutions with robust research networks and interdisciplinary collaborations are more likely to foster innovation in sustainable practices (Cabanillas-Carbonell et al., 2023). The preeminence of universities from China, Italy, Bangladesh, and India corresponds with their status as significant contributors to the global leather industry, necessitating sustainable solutions to alleviate environmental repercussions (UNIDO, 2021). The heightened scholarly emphasis on this subject signifies escalating regulatory demands and market demand for sustainable and ethically sourced leather products (Chen et al., 2023).

The picture illustrates the geographical distribution of research endeavors, with institutions from Asia and Europe spearheading contributions. This underscores the significance of global collaboration and knowledge exchange to attain sustainable objectives in the leather sector. Subsequent study may investigate the impact of institutional relationships and financing on research output in this domain.

Documents by affiliation

Compare the document counts for up to 15 affiliations.

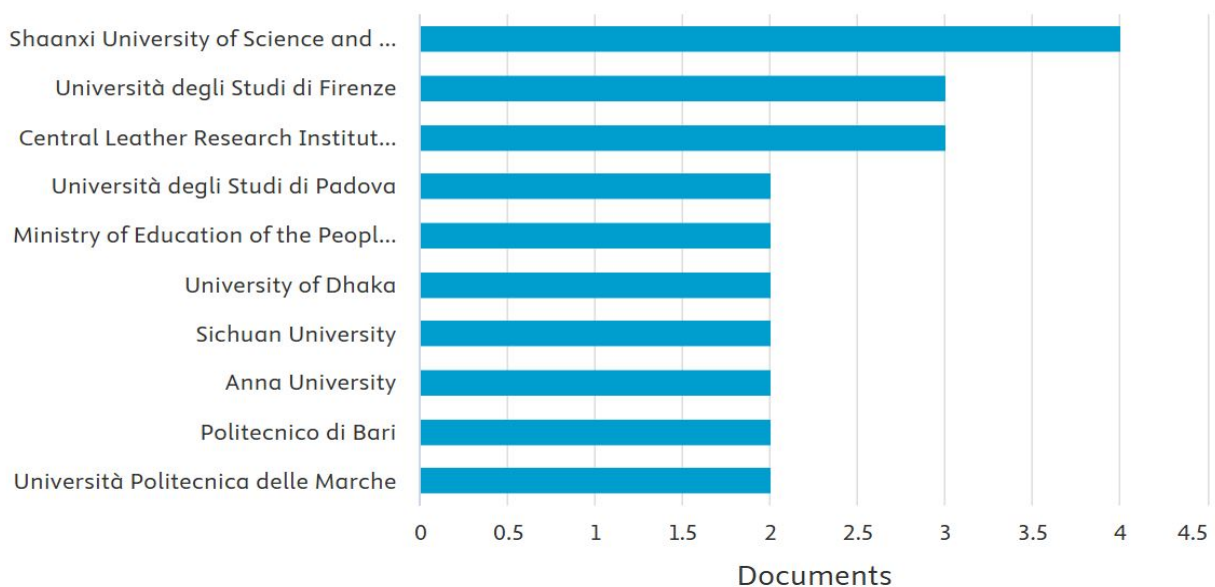


Figure 4: Document by Affiliations

Documents by Subject Area

Figure 5 illustrates the allocation of research contributions among diverse subject areas, emphasizing the multidisciplinary character of the study. The Business, Management, and Accounting category comprises the biggest proportion of documents (21.4%), indicating a growing interest in sustainability-oriented business models, circular economy activities, and the financial ramifications of sustainable leather manufacturing. This corresponds with research highlighting the significance of green supply chain management and sustainable finance in resource-intensive sectors (Kumar et al., 2022).

Environmental Science (20.3%) and Energy (17.7%) constitute substantial segments of the research emphasis, signifying that sustainability and energy efficiency are crucial to the discourse. Research indicates that conventional leather manufacturing is resource-demanding and leads to considerable environmental pollution (Rashid et al., 2021). Consequently, research in these domains likely investigates renewable energy solutions, waste minimization, and sustainable production methodologies. The Engineering sector (17.2%) further substantiates this, as innovations in chemical engineering, materials science, and waste treatment technologies are crucial in fostering sustainable practices.

Additional disciplines, such as Social Sciences (8.9%) and Economics (5.7%), underscore the socio-economic implications of sustainable leather manufacturing. Research in these domains may concentrate on consumer behavior, labor market ramifications, and legislative structures that facilitate sustainable developments within the business. The representation of Computer Science (3.1%) and Materials Science (3.1%) indicates a burgeoning emphasis on digitalization and novel material solutions, including bio-based alternatives and intelligent manufacturing processes (Tripathi et al., 2024).

The incorporation of Decision Science (1.0%) and Arts and Humanities (1.6%) signifies that sustainability in the leather sector is being examined via an ethical and strategic decision-making lens. This corresponds with recent dialogues regarding corporate social responsibility (CSR) and ethical consumption, which affect market demand for sustainable leather products (De Klerk et al., 2019).

The image demonstrates a multidisciplinary research method that combines business, environmental science, and engineering to tackle sustainability issues in the leather industry. Future research could gain from more profound collaborations among these disciplines to improve technology advances, policy frameworks, and commercial strategies that underpin a circular economy.

Documents by subject area

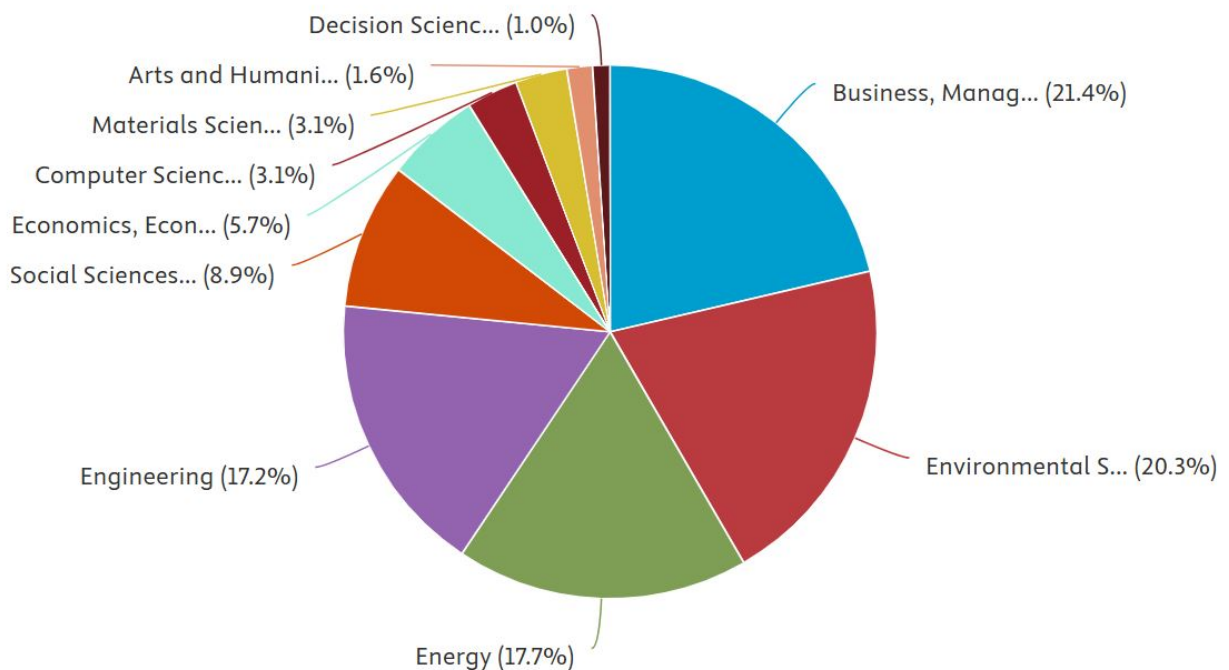


Figure 5: Documents by subject area

Co-authorship Network by Country

Figure 6 illustrates a co-authorship network by nation, created with VOSviewer, to depict global research collaboration. The size of each node represents the volume of research publications, while the thickness of the links indicates the strength of collaboration between countries. The color-coded clusters indicate separate regional research networks, demonstrating the interconnectivity of global academic institutions.

The co-authorship network offers insights into the global research scene, especially in areas pertinent to sustainability, circular economy, and industrial innovation. The identified collaboration patterns indicate that industrialized nations, including Italy, Germany, and the United States, are prominent contributors, establishing robust networks with rising economies such as India, Pakistan, and Iran. This corresponds with other studies, highlighting that knowledge transfer between developed and poor nations is essential for fostering sustainable innovation (Chen et al., 2023).

Italy plays a pivotal role, demonstrating robust research connections with Germany, Brazil, and the United States. This indicates that Italy plays a pivotal role in international academic collaboration, especially in areas concerning sustainability, industrial innovation, and technological progress. India, in conjunction with Malaysia, Pakistan, and Iran, is a closely integrated regional research cluster, underscoring dynamic knowledge flow across South Asia.

The United States and Canada preserve a robust bilateral research partnership, frequently encompassing European countries, which underscores their impact on worldwide intellectual dialogue. Conversely, Chile and Mexico exhibit intra-regional collaboration

within Latin America, however possess comparatively weaker global connections. Extending research networks beyond regional confines may augment their scholarly influence internationally.

This visualization highlights the significance of global cooperation in promoting research and innovation. Although rich nations maintain dominance in global research networks, enhancing collaborations with emerging economies can promote inclusive and equitable knowledge generation. Promoting cross-border funding, academic exchange programs, and collaborative research initiatives will be crucial in tackling global concerns such as sustainability, digital transformation, and economic development.

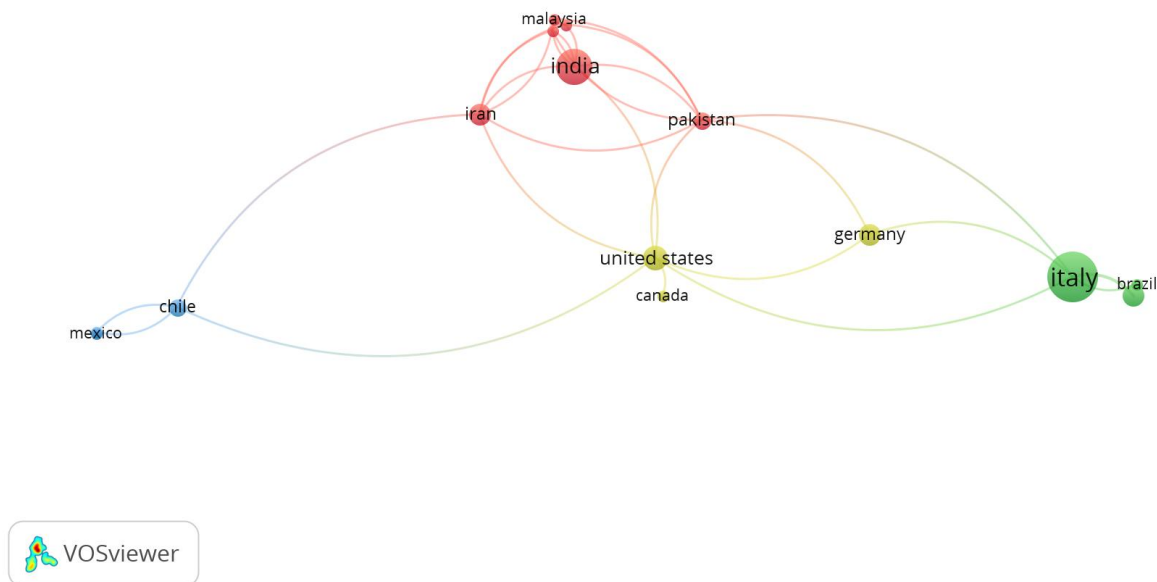


Figure 6: Co-authorship network by country

Co-citation of Network of Cited Authors

Figure 7 depicts the frequency with which various authors are co-cited in academic literature, thereby representing the conceptual framework and knowledge foundation of a research domain. Co-citation analysis, first presented by Robledo-Giraldo et al. (2023), is a prevalent bibliometric method for delineating research trends and recognizing prominent scientists.

The visualization consists of multiple clusters, represented in different colors (red, blue, and green), which indicate groups of authors frequently cited together. The dimensions of the nodes (author names) reflect their citation frequency, with larger nodes signifying more frequently referenced authors. The connections (edges) between nodes signify co-citation relationships; the greater the thickness of the link, the more robust the co-citation relationship between the two authors. The red cluster on the left comprises researchers such as Puig R., Ulgiati S., Kanagaraj J., and Nair B. U., indicating that their contributions are part of a unique research stream, potentially establishing the core theories of the discipline. The core blue cluster includes writers like Maj J. and Wang Y., who serve as intermediaries,

linking foundational theories to emerging research. The green cluster on the right, comprising authors such as Shi B., Yu Y., Wang Y. N., and Wang X. C., exhibits the highest degree of interconnectivity, indicating that these researchers embody a nascent or prevailing research theme characterized by frequent cross-referencing.

The existence of different clusters and bridging writers carries significant theoretical and practical ramifications. The red cluster probably denotes classical theories or foundational works that established the discipline, whereas the green cluster indicates a more contemporary study area garnering heightened academic interest. The blue cluster serves an integrative function, promoting the advancement of knowledge by connecting established and contemporary research paradigms. This pattern corresponds with established literature on knowledge dissemination, indicating that scientific advancement is predicated on foundational theories, subsequently integrated and augmented by novel research (Chen et al., 2023).

Understanding the co-citation network is valuable for various stakeholders in academia. It assists researchers in identifying foundational works and new scholars, facilitating a better organized literature review and research placement. Policymakers and funding organizations can utilize the identification of highly cited authors and interconnected clusters to direct resource allocation towards significant research domains. Furthermore, recognizing under-connected clusters might promote interdisciplinary cooperation, facilitating the amalgamation of varied ideas.

In summary, the co-citation network offers an extensive depiction of information dissemination within a study domain, emphasizing both fundamental and nascent research fields. The structure of the network helps scholars navigate existing literature while identifying gaps and opportunities for future study.

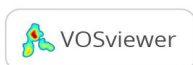
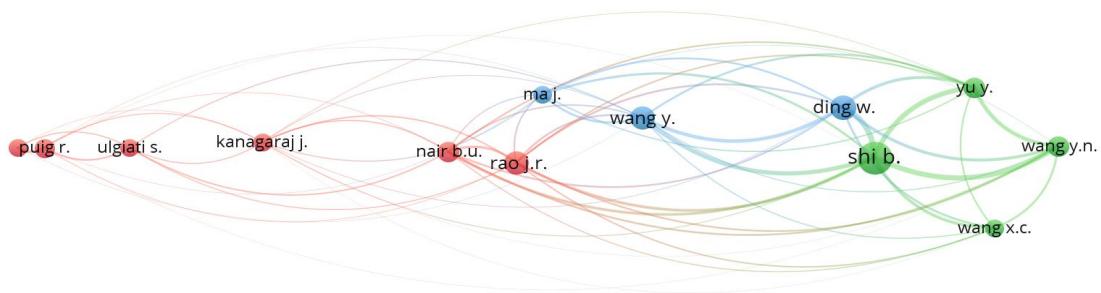


Figure 7: Co-citation of Network of cited Authors

Bibliographic Coupling of Authors

The bibliographic coupling visualization illustrates a sophisticated network of research connections among writers investigating sustainable leather production in South Asia. Figure 8 presents a network map produced by VOSviewer, depicting the intellectual connections among researchers based on their citation patterns, with various colored groupings signifying unique research communities or thematic domains.

Upon studying the network structure, various unique clusters may be observed. The red cluster comprises scholars such as Marrucci L., Corcelli F., and Hildebrandt J., who concentrate on environmental impact assessment and life cycle analysis in leather production. This group's efforts primarily focus on the initial research objective of delineating trends in leather production, especially in relation to environmental sustainability indicators. These authors often reference analogous sources, signifying their common theoretical underpinnings and methodological strategies.

The green cluster, which includes scholars such as Hittini W. and Ariram N., focuses on the technological dimensions of sustainable leather processing and waste management. Their bibliographic coupling indicates a significant emphasis on innovative technology and cleaner production techniques, consistent with the study's aim of identifying principal themes and issues in sustainable leather production. This connection is especially pertinent due to the industry's urgent demand for technology solutions to environmental issues.

The blue cluster, featuring writers such as Ouyang M. and Hu K., appears to focus on supply chain management and the economic dimensions of sustainable leather production. Their research seems to be primarily concentrated on business models and implementation tactics, enhancing the comprehension of cooperation networks, which is another principal purpose of the study. Kanagaraj et al. (2015) emphasize that these economic views are essential for the implementation of sustainable practices in the leather industry in South Asia.

The purple cluster, however smaller, features authors such as Ding and Liu engaged in specialized domains, likely concentrating on technical advancements or regional case studies. Their role in the network indicates they may be tackling research deficiencies, which corresponds with the study's fourth purpose of emphasizing research gaps and prospective avenues.

The linkages among clusters are especially significant. Authors such as Beghetto V. and Agostinis I. seem to connect various clusters, indicating that their research synthesizes many elements of sustainable leather production. This interdisciplinary approach is essential, as sustainable leather production necessitates solutions that integrate environmental, technical, and economic factors (Dixit et al., 2015).

This bibliographic coupling study elucidates both strengths and possibilities within the research environment. Although much research exists on technological and environmental dimensions, there may be an opportunity for more comprehensive studies that incorporate many views. This corresponds with Omoloso et al.'s (2021) assertion that comprehensive strategies are essential for promoting sustainable practices in the leather sector.

The graphic indicates potential for enhanced collaboration within clusters, especially between technical researchers and those concentrating on implementation techniques. Such collaborations could facilitate the convergence of theoretical solutions and practical application, a significant difficulty in South Asia's leather industry.

This analysis provides valuable insights for future research directions, suggesting the need for more integrated studies that combine environmental, technical, and economic perspectives. It underscores the necessity of fortifying worldwide research networks to tackle the intricate issues of sustainable leather production in South Asia.

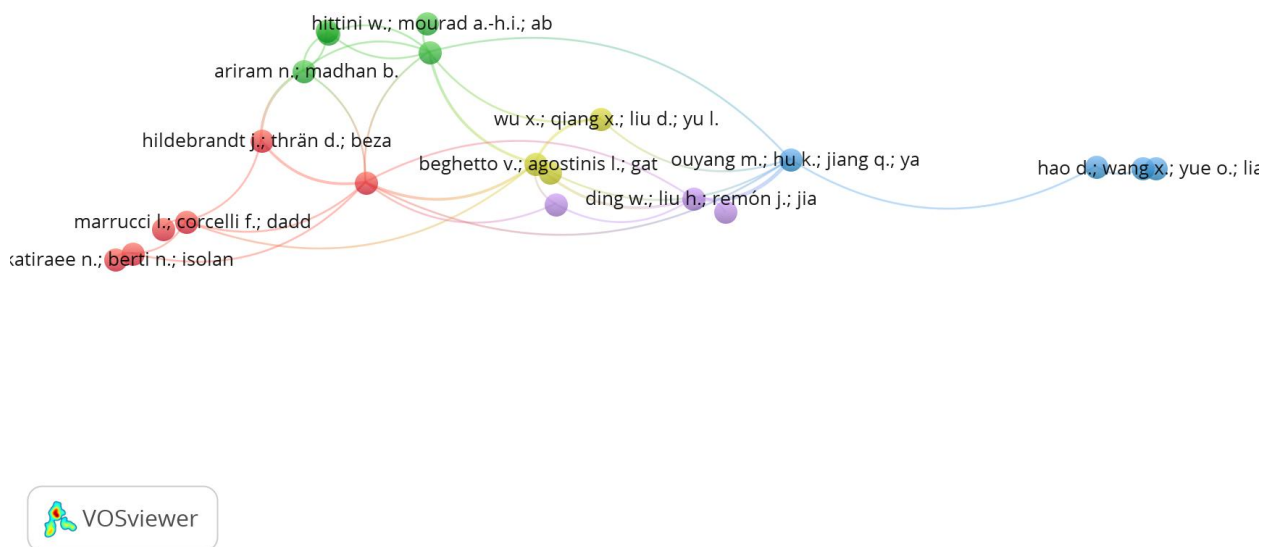


Figure 8: Bibliographic coupling of authors

Co-occurrence of all keywords

Figure 9 illustrates the co-occurrence network of terms, as visualized by VOSviewer, emphasizing important study subjects and their interrelations in sustainable leather manufacturing in South Asia. The network is organized into three separate clusters, each signifying a unique research emphasis.

The red cluster focused on "sustainable development," "leather," and "circular economy," constitutes the fundamental theoretical framework of the research. This cluster highlights the increasing significance of sustainability in leather production, in accordance with industry trends favoring closed-loop manufacturing methods. The robust connection between "circular economy" and "environmental sustainability" underscores initiatives aimed at improving waste reduction and resource efficiency, as evidenced by recent literature (Karuppiah et al., 2021).

The green cluster, connecting "cleaner production," "leather production," and "wastewater treatment," addresses technical and environmental difficulties. This underscores significant pollution issues in the leather sector, especially regarding wastewater management, a crucial concern as more than 90% of South Asian tanneries face challenges in adequate waste disposal (Omoloso et al., 2021). This cluster highlights the industry's continuous technological initiatives to reduce environmental harm.

The blue cluster, encompassing "textile industry" and "textiles," indicates the relationship between the leather and textile sectors in South Asia. This indicates potential for inter-industry collaboration and knowledge sharing in sustainable practices.

Numerous bridge keywords, such as "tanning," "manufacturing," and "shoe manufacture," interconnect various clusters, illustrating their function as linking concepts in sustainable leather production. The prominence of "sustainable development" underscores its role as a cohesive topic, highlighting the industry's dedication to environmental and social accountability.

The review underscores technical and environmental progress while also pinpointing research deficiencies in social sustainability and creative technologies. Rectifying these deficiencies would correspond with the study's aim of investigating prospective research avenues in sustainable leather production.

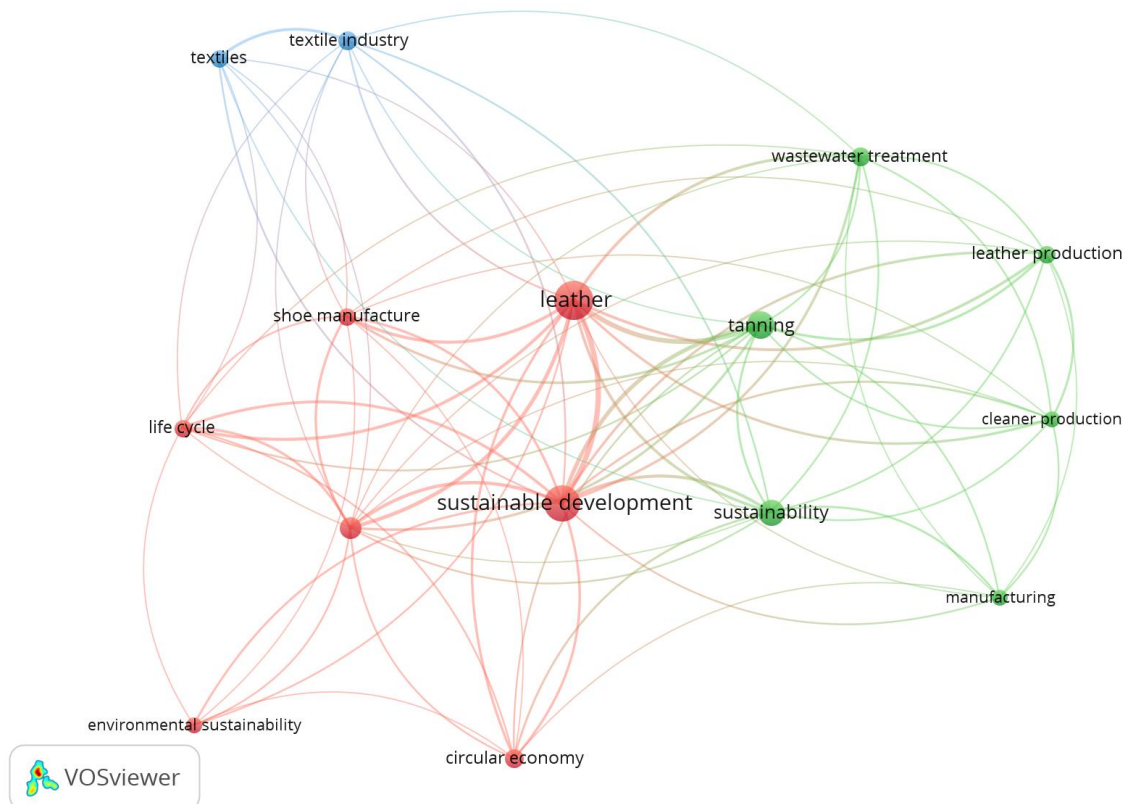


Figure 9: Co-occurrence of all keywords

Table 2: Reporting of some relevant articles towards the topic

Title	Author and Year	Objectives of the study	Findings
Transition to Sustainable Development in the Tanning Industry: Evidence from Leather Value Chain in Tamil Nadu, India	Paul et al., 2023	The study aims to investigate the environmental, economic, and social challenges facing the leather value chain and examine the impact of adopting eco-friendlier and sustainable methods of production. Specifically, the paper seeks to understand how the industry can move away from conventional tanning practices, which are environmentally harmful, towards greener alternatives that reduce pollution and water usage.	The findings of the study suggest that while sustainable practices can lead to significant environmental benefits, including reduced water consumption and pollution, their widespread adoption is still hampered by several challenges. These include the high costs associated with transitioning to sustainable technologies and the lack of adequate infrastructure in the industry. However, the research highlights that there are considerable opportunities for the leather industry to reduce its environmental impact by embracing eco-friendly technologies, particularly driven by policy support, market demand, and international trade regulations.
Trends and Advancements in Sustainable Leather Processing: Future Directions and Challenges—A Review	Kanagaraj et al., (2020)	The study aims to provide an overview of the recent innovations in leather production methods that focus on reducing environmental impact, including the adoption of cleaner technologies and eco-friendly materials. It explores the significance of sustainable practices in improving both the environmental footprint and the socio-economic conditions within the leather industry.	The findings of the study reveal that there has been considerable progress in sustainable leather processing technologies, particularly in areas such as waste management, water conservation, and the reduction of toxic chemical usage. However, the transition to greener practices faces several challenges, including high implementation costs, a lack of proper infrastructure, and limited consumer awareness regarding sustainable leather products.
The Circularity of Potential Bio-Textile Production Routes: Comparing Life Cycle Impacts of Bio-Based Materials Used Within the Manufacturing of Selected Leather Substitutes	Hildebrandt et al., (2021)	The study compares the environmental performance of various bio-textile production routes, evaluating their sustainability potential and how these alternatives could contribute to reducing the ecological footprint of the leather industry. The primary aim of the study is to explore the viability of bio-based substitutes for leather, emphasizing their potential for circularity and sustainable production.	The findings of the study indicate that bio-based leather alternatives can offer significant environmental benefits compared to conventional leather, particularly in terms of reducing carbon emissions and resource consumption. The research shows that certain bio-textile materials have lower life cycle impacts, including reduced energy use and water consumption. However, the study also highlights that the overall sustainability of these alternatives depends on factors such as sourcing, production methods, and end-of-life management.
Making Deforestation Risk Visible: Discourses on Bovine Leather	Mammadova et al., (2020)	The study investigates how deforestation, particularly related to cattle ranching and leather production, is framed	The findings of the study reveal that deforestation risks related to the leather supply chain are often downplayed or ignored by certain

Supply Chain in
Brazil

within public and industry discourses. The primary aim of the research is to explore how these discourses shape the perception and response to the environmental impacts of leather production, with a particular focus on Brazil, one of the largest producers of bovine leather in the world.

industry stakeholders, even though the environmental impacts of leather production are well-documented. The research highlights a complex relationship between the leather industry, agriculture, and environmental protection policies in Brazil. While some actors in the supply chain acknowledge the issue, others prioritize economic and market pressures over environmental concerns. The study concludes that there is a need for greater transparency and accountability within the leather supply chain, along with more stringent regulations, to mitigate the deforestation risks associated with leather production.

Novel Biomass-Based Polymeric Dyes: Preparation and Performance Assessment in the Dyeing of Biomass-Derived Aldehyde-Tanned Leather

Ding et al., (2023)

This study focuses on the development and evaluation of biomass-based polymeric dyes for use in the dyeing of aldehyde-tanned leather. The study explores the potential of using bio-derived dyes as an alternative to synthetic dyes in leather processing, aiming to improve the sustainability of the dyeing process in the leather industry. The primary objective is to assess the preparation methods and performance of these novel biomass-based dyes in terms of color strength, fastness, and environmental impact.

The findings of the study indicate that the biomass-based polymeric dyes offer several advantages over traditional synthetic dyes, including improved environmental performance, lower toxicity, and better biodegradability. The research demonstrates that these bio-based dyes provide strong color retention and fastness in leather, making them suitable for use in industrial applications. Additionally, the study highlights the potential for reducing the environmental footprint of the leather dyeing process by substituting petrochemical-based dyes with renewable, biomass-derived alternatives.

Nanomaterials to Help Eco-Friendly Leather Processing

Kopp et al., (2021)

This study explores the potential use of nanomaterials in the leather industry to make the processing methods more environmentally friendly. The study aims to investigate how nanotechnology can be applied to improve the leather tanning process, reduce the environmental impact, and make it more sustainable. The primary focus is on identifying specific nanomaterials that could replace or reduce the use of traditional, harmful chemicals in leather

The findings of the study indicate that nanomaterials, such as nanoclays, nanofibers, and nanoparticles, offer significant advantages in eco-friendly leather processing. These materials can enhance the efficiency of tanning processes, improve the physical properties of leather, and reduce the consumption of chemicals, water, and energy. The research demonstrates that nanomaterials can be used to modify the leather's properties, making it more durable, flexible, and resistant to wear and tear. Additionally, the

			processing, such as chromium and other toxic substances.	study highlights that the use of nanomaterials can also help in achieving better color fixation during dyeing, leading to reduced chemical waste.
Circular Economy Practices in the Leather Industry: A Practical Step Towards Sustainable Development	Moktadir et al., (2020)	This study investigates how circular economy principles can be implemented in the leather industry to achieve more sustainable production practices. The study aims to evaluate the current state of circular economy practices within the leather industry and explore how these practices can contribute to minimizing waste, improving resource efficiency, and reducing the environmental footprint of leather production.		The findings of the study indicate that the leather industry, which is traditionally resource-intensive, can significantly benefit from the adoption of circular economy practices. These practices, such as waste recycling, reusing leather scraps, and using renewable materials, can help reduce the industry's environmental impact by minimizing waste and enhancing resource recovery. The research highlights several successful case studies where leather manufacturers have implemented circular economy principles, resulting in reduced water usage, lower chemical waste, and improved sustainability.
Fostering Green Finance for Sustainable Development: A Focus on Textile and Leather Small Medium Enterprises in Pakistan	Kumar et al., (2022)	This study explores the role of green finance in promoting sustainable development in the textile and leather small and medium-sized enterprises (SMEs) in Pakistan. The study aims to assess how green finance mechanisms, such as loans, investments, and grants dedicated to environmentally friendly initiatives, can support the adoption of sustainable practices in Pakistan's textile and leather industries. The primary objective is to identify the barriers to accessing green finance for SMEs and propose strategies to overcome these challenges.		The findings of the study indicate that while green finance holds significant potential to promote sustainability within the textile and leather sectors in Pakistan, several barriers impede its effective implementation. These barriers include limited access to financial resources, a lack of awareness of green finance options, and insufficient government incentives to encourage the adoption of eco-friendly practices. The research highlights that SMEs often struggle with the high upfront costs of sustainable technologies and the perceived risks associated with transitioning to greener operations.
Mitigating Tannery Pollution in Sub-Saharan Africa and South Asia	Hira et al., (2020)	This study focuses on the environmental challenges posed by tannery pollution in sub-Saharan Africa and South Asia, two regions with significant leather production industries. The study aims to evaluate the impact of tannery pollution on the environment and public health in these regions, and to explore potential strategies and technologies for mitigating		The findings of the study indicate that tannery pollution remains a major issue in both sub-Saharan Africa and South Asia, with significant environmental and health risks due to the discharge of untreated effluents containing toxic chemicals, such as chromium, into water bodies. The study highlights that current pollution control measures are often inadequate, primarily due to a lack of proper infrastructure,

		pollution and improving sustainability in leather production.	weak enforcement of environmental regulations, and limited awareness of sustainable practices among small-scale tannery operators. However, the research also identifies several promising solutions, such as the introduction of cleaner technologies, the use of eco-friendly tanning agents, and the implementation of waste management systems that reduce water and chemical usage.
Progress in Sustainable Technologies of Leather Wastes Valorization as Solutions for the Circular Economy	Chojnacka et al., (2021)	This paper examines the advances in sustainable technologies for the valorization of leather wastes within the context of a circular economy. The study aims to explore the various methods of reusing and recycling leather waste, turning it into valuable products, and thereby contributing to a more sustainable leather industry.	The findings of the study indicate that there has been significant progress in the development of sustainable technologies for leather waste valorization. These technologies include the conversion of leather waste into bio-based products such as collagen, gelatin, and bioplastics, which can be used in a variety of industrial applications. The research shows that recycling leather waste not only reduces the environmental impact of the leather industry by decreasing waste and the use of natural resources, but also offers new economic opportunities.
"Inhibitors to Circular Economy Practices in the Leather Industry Using an Integrated Approach: Implications for Sustainable Development Goals in Emerging Economies	Karuppiah et al., (2021)	This study examines the barriers to the adoption of circular economy practices within the leather industry, particularly in emerging economies. The study aims to identify the factors that hinder the transition to circular economy models in leather production and analyze the implications for achieving sustainable development goals (SDGs) in these regions.	The findings of the study reveal several key inhibitors to the adoption of circular economy practices in the leather industry, including financial constraints, lack of technological infrastructure, and insufficient regulatory frameworks in emerging economies. The study also identifies challenges such as low consumer awareness, resistance to change from traditional production methods, and inadequate supply chain integration. These factors create significant barriers to the widespread implementation of circular practices, such as recycling, waste reduction, and resource reuse.
Circular Economy and Opportunities for SMEs in Leather Industry of Pakistan	Akbar et al., (2025)	This paper explores the potential of implementing circular economy principles within the small and medium-sized enterprises (SMEs) in Pakistan's leather industry. The	The findings of the study suggest that SMEs in Pakistan's leather industry face several challenges in adopting circular economy practices, including limited financial resources, a lack of

		study aims to assess the opportunities and challenges faced by SMEs in adopting circular economy practices and how these can contribute to enhancing the sustainability of the leather sector in Pakistan.	technical expertise, and insufficient awareness of circular economy principles. However, the research also highlights significant opportunities for SMEs, such as cost savings from resource efficiency, increased competitiveness in global markets due to sustainable practices, and the potential for new business models based on waste reuse and recycling. The study emphasizes that for SMEs to successfully transition to a circular economy, they need support in the form of government incentives, access to green financing, and capacity-building initiatives.
Understanding the Drivers of Sustainable Entrepreneurial Practices in Pakistan's Leather Industry: A Multi-Level Approach	Wahga et al., (2018)	This paper investigates the factors that drive sustainable entrepreneurial practices within Pakistan's leather industry. The study aims to explore the multi-level drivers, including individual, organizational, and institutional factors, that influence the adoption of sustainable business practices by entrepreneurs in the leather sector.	The findings of the study indicate that sustainable entrepreneurial practices in Pakistan's leather industry are driven by a combination of internal and external factors. At the individual level, entrepreneurs are motivated by personal values and the desire to contribute to environmental and social sustainability. At the organizational level, the adoption of sustainable practices is influenced by the availability of resources, leadership commitment, and the integration of sustainability into business strategies. At the institutional level, government regulations, market pressures, and international trade requirements play a significant role in encouraging sustainable practices. However, the study also identifies barriers to sustainability, including the lack of awareness about sustainable practices, limited access to financial resources, and weak enforcement of environmental regulations.
Walking the Talk: Unraveling the Influence of the Sustainability Features of Leather Alternatives on Consumer Behavior toward Running Shoes	Yadav et al., (2024)	This paper explores how the sustainability attributes of leather alternatives affect consumer purchasing decisions in the context of running shoes. The study aims to understand the role of eco-friendly features in leather substitutes, such as biodegradability, resource efficiency, and reduced	The findings of the study indicate that sustainability features of leather alternatives have a significant influence on consumer behavior, particularly among environmentally-conscious consumers. The research shows that attributes like biodegradability, low carbon footprint, and the use of

		environmental impact, in shaping consumer attitudes and behaviors.	renewable resources are highly valued by consumers, and they play a critical role in the decision-making process when purchasing running shoes. However, the study also highlights that while sustainability features are important, other factors such as price, comfort, and brand reputation also play crucial roles in consumer decisions.
Towards Sustainable Supply Chain Management (SSCM): A Case of Leather Industry	Islam et al., (2020)	The study aims to investigate how the leather sector can adopt sustainable practices across its supply chain, from raw material procurement to the final product. The primary objective is to identify key sustainability challenges and opportunities within the leather supply chain and to suggest strategies for improving environmental, social, and economic performance in this industry.	The findings of the study highlight that the leather industry faces significant sustainability challenges, including waste management, environmental pollution, and unethical labor practices, which can hinder the effectiveness of supply chain operations. The research shows that implementing SSCM practices can help mitigate these issues by promoting environmentally friendly processes, such as cleaner production methods, waste reduction, and the use of sustainable raw materials.

Table 3. Development of themes

Terms from Bibliographic Mappings	Key Terms Derived from the 14 Papers	1 st Level Filtration and Association	2 nd Level Filtration and Association	Themes
Human resource management, Social networking (online), Sustainable entrepreneurship, Investment, Crowdfunding, Technology, Innovation systems, Information systems, Entrepreneurship, Sustainable development, Social finance, Social venture, Model paper, Regulation, Framework, Innovation, Technology-based solutions	Environmental challenges, Circular economy, Sustainable production, Bio-based materials, Nanomaterials, Water conservation, Eco-friendly dyes, Waste management, Sustainable supply chain, Green finance, Cleaner technologies, Consumer behavior, Deforestation risks, Leather alternatives	Information systems, innovation, advancement in information and communication technologies, growth of FinTech, technological solutions for sustainability, solutions for sustainable competitive advantage in businesses. Social networking (online), social entrepreneurship, social finance, socioeconomic challenges, growth of small enterprises, role of information technology.	Circular economy, environmental sustainability, waste reduction, resource efficiency. Technological innovations in cleaner production, waste management, resource use, eco-friendly alternatives.	Circular Economy
		Human capital, green technologies, investment in eco-friendly solutions, knowledge sharing.	Technological advancements, industry trends, supply chain collaboration, sustainable business models.	Innovative Technologies
				Supply Chain Collaboration

Themes in Sustainable Leather Production

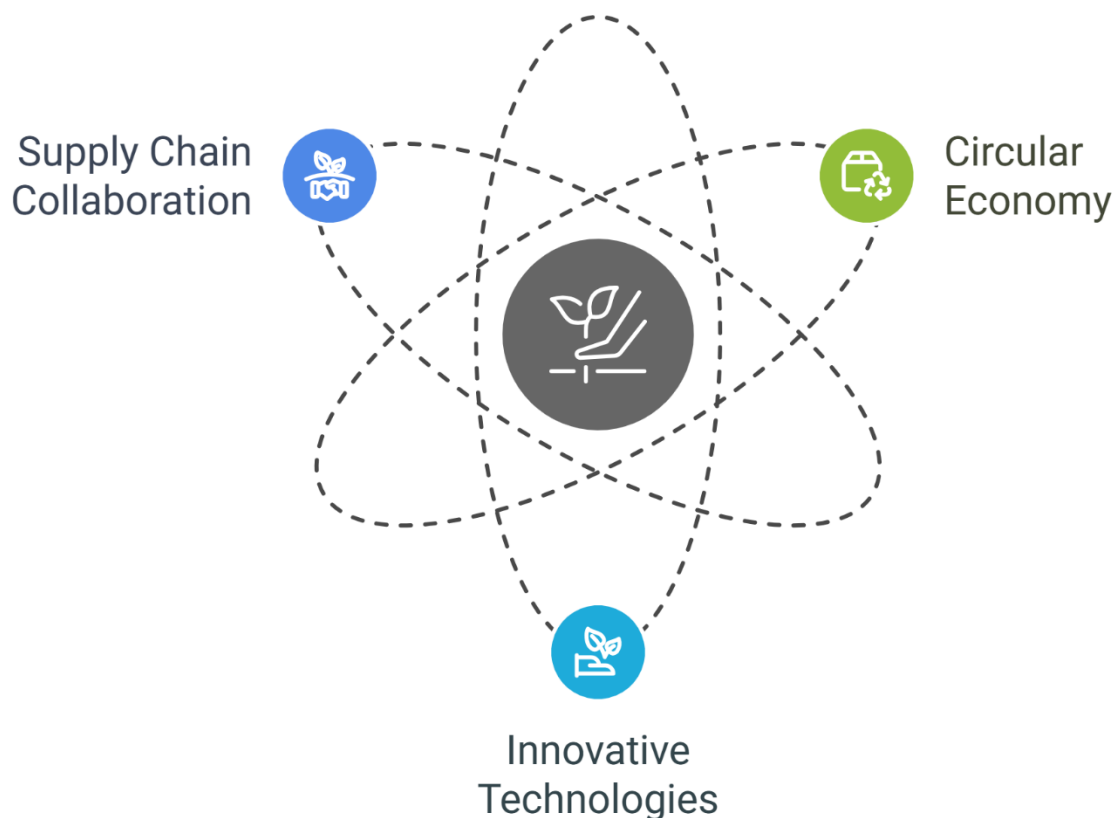


Figure 10: Themes in Sustainable Leather Production

Discussion on the Three Themes in Sustainable Leather Production

The shift to sustainable leather production is intricate and multifarious, encompassing numerous problems and opportunities within the process. This discussion focuses on three principal themes outlined in Table 3 and Figure 10: Circular Economy, Innovative Technologies, and Supply Chain Collaboration. Each of these aspects is essential in influencing the course of sustainable leather production and must be meticulously addressed for the industry to progress towards a more sustainable future.

Circular Economy

The circular economy idea is crucial to sustainable leather production, as it prioritizes waste reduction, enhanced resource efficiency, and the establishment of closed-loop systems. Applying circular economy principles in leather production entails creating items that are reusable, recyclable, or biodegradable, hence diminishing the industry's overall environmental impact. The difficulty resides in the significant transformation needed in both business models and production methodologies.

Numerous studies highlight the efficacy of circular economy strategies, especially in resource efficiency and waste minimization. The manufacture of leather is resource-intensive, requiring substantial amounts of water, energy, and chemicals. Industrial waste management systems frequently do not comply with environmental regulations, resulting in contamination and considerable resource loss. Implementing circular economy strategies may alleviate these issues by promoting the recycling of leather waste, the recovery of valuable materials, and the establishment of zero-waste systems inside organizations. Nonetheless, the expansion of these techniques is challenging without adequate infrastructure, which is still deficient in numerous regions, particularly in emerging nations (Kanagaraj et al., 2020). Moreover, the absence of technical proficiency and the reluctance to embrace new methods are significant obstacles.

Notwithstanding these limitations, the circular economy offers a crucial avenue for mitigating the environmental impact of the leather industry. Companies can enhance environmental sustainability by prioritizing resource efficiency, sustainable raw material procurement, and robust recycling initiatives. Achieving these targets necessitates substantial investment in infrastructure, technology, and regulatory assistance (Moktadir et al., 2020).

Innovative Technologies

Advancements in production technology are a vital factor propelling sustainable practices within the leather industry. Technological improvements can mitigate the environmental impact of leather tanning and production through the implementation of cleaner procedures and materials. The advancement of alternative tanning chemicals, including vegetable and enzyme-based options, together with improvements in waste management technologies, has demonstrated potential in enhancing the eco-friendliness of the leather production process (Hira et al., 2020).

Nonetheless, although these breakthroughs provide a route to sustainability, significant technological obstacles impede their extensive use. A major obstacle is the substantial expense associated with the implementation of these technologies. Numerous sustainable technologies necessitate substantial initial capital, which smaller manufacturers, especially in poorer nations, may lack the financial capacity to finance. The restricted supply of skilled personnel and technical expertise further hinders the implementation of these new techniques (Kanagaraj et al., 2020). Kopp et al. (2021) emphasize the necessity for scalable solutions that can be readily applied across various production scales to enhance the whole sector.

Notwithstanding these obstacles, technical innovation is essential for attaining sustainability in the leather sector. Advancements in cleaner technology, including eco-friendly dyes, waste-to-value solutions, and enhanced water utilization strategies, present significant opportunities for diminishing the industry's ecological imprint. Nonetheless, expanding these breakthroughs and guaranteeing their economic feasibility would necessitate increased investment, research, and cooperative endeavors among scholars, industry stakeholders, and governments.

Supply Chain Collaboration

The leather supply chain is frequently disjointed, including numerous participants at various stages, from raw material procurement to final product distribution. This fragmentation poses a considerable obstacle to the implementation of sustainable practices throughout the whole supply chain. To attain sustainability in the leather sector, it is imperative that all

stakeholders, including suppliers, manufacturers, and retailers, collaborate to implement eco-friendly practices and comply with sustainability requirements (Moktadir et al., 2020).

Collaboration throughout the supply chain guarantees that sustainable practices are adopted not just in production but also in sourcing, waste management, and the disposal of final goods. Businesses must verify that raw materials utilized in leather manufacture are procured from environmentally responsible farms adhering to ethical principles. Moreover, producers must partner with waste management facilities to guarantee the recycling of leather remnants and the secure disposal of chemical by-products. Clear communication and information dissemination across the supply chain are essential for guaranteeing that every phase of production aligns with sustainability objectives (Akbar et al., 2025).

Nonetheless, supply chain collaboration is frequently obstructed by commercial motivations, insufficient trust, and inadequate regulatory frameworks. Minor producers may lack the finances or motivation to invest in sustainable methods, whereas large-scale producers may emphasize profit over sustainability. To tackle these difficulties, it is imperative to set explicit sustainability standards, provide incentives for sustainable behaviors, and enhance coordination among supply chain partners. By promoting collaboration throughout all tiers of the supply chain, the leather industry may shift towards more sustainable production paradigms (Islam et al., 2020).

The three themes of Circular Economy and Resource Efficiency, Innovative Technologies for Sustainable Production, and Supply Chain Collaboration for Sustainable Business Models are essential for advancing sustainability in the leather sector. Despite considerable hurdles in the business, including elevated costs, inadequate infrastructure, and opposition to change, the implementation of these themes can yield major environmental and economic advantages. Addressing these obstacles necessitates a comprehensive strategy encompassing technical advancement, enhanced investment, robust regulatory structures, and cooperative initiatives throughout the supply chain. By confronting these difficulties, the leather industry can attain enduring sustainability, fostering a cleaner, more ethical, and economically viable future (Hira et al., 2020).

Challenges addressed in existing research for sustainable leather production.

The current study on sustainable leather manufacturing identifies numerous problems encountered by the industry in its shift towards more sustainable practices, as seen in Figure 11. The following are the principal challenges identified:

High Costs of Sustainable Technologies

Implementing sustainable practices, like eco-friendly tanning methods and waste management systems, frequently incurs significant initial expenses. Numerous leather manufacturers, particularly small-scale businesses, encounter financial limitations that hinder their use of these technologies. The expense associated with adopting more sustainable practices, including bio-based tanning agents or sophisticated waste treatment systems, constitutes a substantial obstacle to implementation (Kanagaraj et al., 2020; Hira et al., 2020).

Lack of Adequate Infrastructure

Numerous places, particularly in developing countries, exhibit insufficient infrastructure to facilitate sustainable leather production. This encompasses inadequacies in waste management systems, water treatment facilities, and supply chain logistics capable of supporting sustainable practices. Inadequate infrastructure hinders manufacturers from

adopting circular economy ideas or using cleaner production techniques (Moktadir et al., 2020).

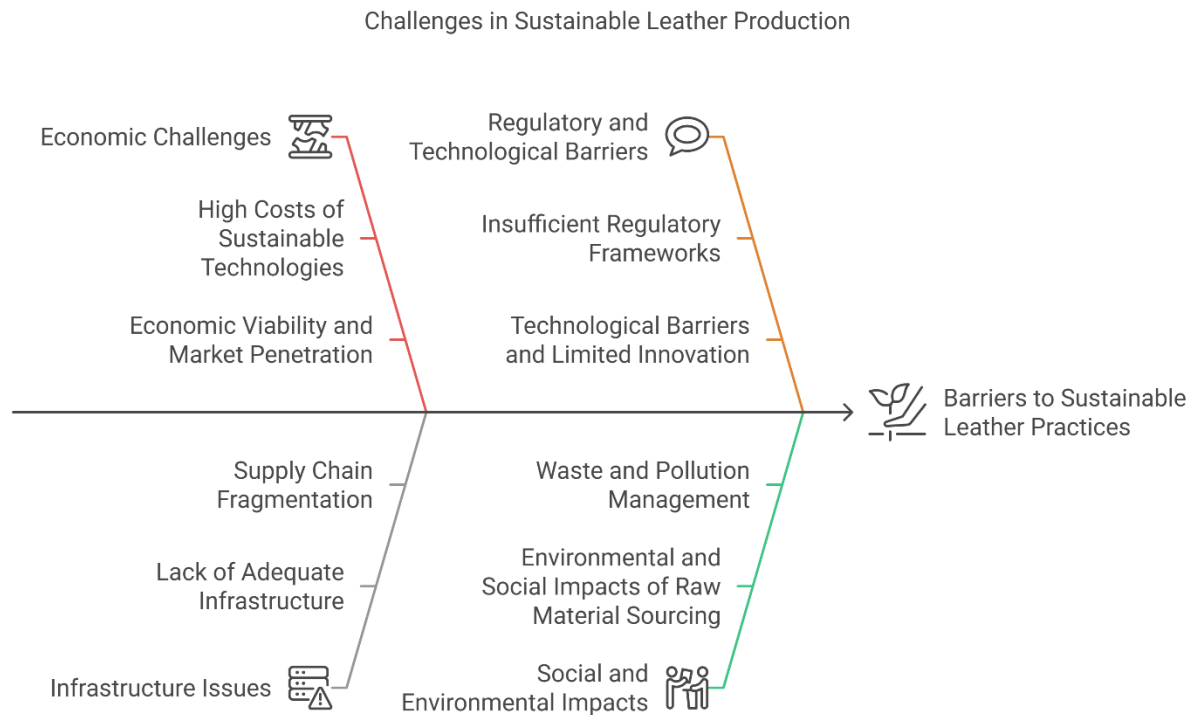


Figure 11: Challenges in sustainable leather production

Insufficient Regulatory Frameworks

The leather business encounters insufficient enforcement of environmental standards, particularly in underdeveloped nations. Insufficient regulation and lax enforcement of environmental norms frequently lead to the persistent utilization of detrimental practices, like chrome tanning and excessive water consumption. In the absence of rigorous regulatory frameworks and incentives for sustainable practices, the industry lacks sufficient motivation to alter its operations (Islam et al., 2020; Mammadova et al., 2020).

Technological Barriers and Limited Innovation

Despite the existence of potential sustainable technologies, such as alternative tanning agents and waste recycling processes, their implementation is frequently obstructed by insufficient technical expertise, restricted innovation within the industry, and the necessity for additional research to render these technologies commercially feasible. Numerous conventional tanneries encounter difficulties in adopting more sustainable practices owing to technology deficiencies (Kanagaraj et al., 2020; Kopp et al., 2021).

Consumer Awareness and Demand

A primary obstacle to sustainable leather production is customers' insufficient awareness of the environmental consequences of conventional leather manufacturing and the advantages of environmentally friendly alternatives. Despite the increasing demand for sustainable products, it remains a niche business. A significant number of consumers value price, comfort, and brand recognition over environmental factors, complicating businesses' ability to explain the elevated costs linked to sustainable production processes (Yadav et al., 2024).

Resistance to Change from Traditional Practices

The leather business is rooted on traditional techniques that have persisted for decades. Numerous producers exhibit resistance to change, especially when it necessitates modifying their production techniques, retraining personnel, or investing in new technologies. The reluctance to adapt poses a considerable obstacle, as the industry is sluggish in embracing more sustainable methods (Kanagaraj et al., 2020).

Environmental and Social Impacts of Raw Material Sourcing

Leather manufacture frequently entails considerable environmental consequences, not only during the tanning process but also in the procurement of raw materials, especially from cow ranching. Concerns include deforestation, land degradation, and greenhouse gas emissions from cattle agriculture. Mitigating the environmental and social repercussions of raw material procurement, especially in areas such as South America and South Asia, is crucial for attaining genuinely sustainable leather production (Mammadova et al., 2020; Hira et al., 2020).

Waste and Pollution Management

Leather manufacture is recognized for producing significant quantities of waste, encompassing solid waste, chemical byproducts, and wastewater. Effectively managing this garbage in an ecologically sustainable manner presents a significant problem. Numerous leather-producing areas are deficient in the infrastructure or knowledge required for the appropriate treatment and disposal of waste, resulting in considerable pollution of aquatic resources and landfills (Kanagaraj et al., 2020; Hira et al., 2020).

Supply Chain Fragmentation

The leather supply chain is significantly fragmented, encompassing numerous participants in sourcing, manufacture, and distribution. This complicates the implementation of sustainable practices throughout the entire supply chain. Ensuring compliance with sustainable standards among all suppliers and manufacturers necessitates improved coordination, transparency, and collaboration, which continues to pose challenges in the sector (Kanagaraj et al., 2020; Moktadir et al., 2020).

Economic Viability and Market Penetration

Sustainable leather products frequently incur elevated production costs, rendering them less competitive in a cost-driven market. Producers may find it challenging to provide environmentally sustainable leather at a price that appeals to customers. Furthermore, the market penetration of sustainable leather products is constrained, and numerous firms are uncertain regarding the long-term feasibility of investing in sustainable practices, especially in contrast to less expensive, conventional leather (Akbar et al., 2025).

These challenges illustrate the intricacies of shifting to sustainable practices in the leather industry and emphasize the necessity for coordinated efforts among policymakers, researchers, and industry stakeholders to tackle these issues. Solutions will necessitate technological innovation, enhanced regulatory frameworks, heightened consumer awareness, and collaboration throughout the supply chain.

Research gaps and propose future research directions

Table 4 delineates critical areas where existing research on sustainable leather production in South Asia is inadequate and provides recommendations for future investigations to rectify these deficiencies.

A notable deficiency in the research pertains to the economic feasibility of sustainable technology, especially for small-scale producers in South Asia. Despite the growing significance of sustainable practices like eco-friendly tanning and waste management, numerous smaller businesses encounter financial obstacles that hinder their adoption of these technologies. Kanagaraj et al. (2020) and Akbar et al. (2025) underscore the necessity for forthcoming research to perform cost-benefit assessments to assess the financial viability of sustainable technologies, aiding SMEs in comprehending how to implement environmentally friendly practices while maintaining economic sustainability.

A crucial area of emphasis is the scalability of sustainable tanning agents and waste management solutions. Although alternate tanning agents and waste management options exist, research on making these technologies economically viable and scalable for extensive industry application is restricted. Kopp et al. (2021) and Hira et al. (2020) propose that subsequent research should investigate methods to create scalable solutions applicable across diverse production scales, especially in areas with constrained resources or technological proficiency.

The incorporation of circular economy principles inside the leather supply chain remains a largely unexamined subject. Although circular economy approaches have demonstrated efficacy in minimizing waste and enhancing resource efficiency, there remains a deficiency in study about the application of these principles throughout the full leather production process. Moktadir et al. (2020) and Kanagaraj et al. (2020) advocate for subsequent research investigating the comprehensive incorporation of circular economy techniques across the supply chain, encompassing raw material procurement to the end-of-life management of leather products.

Further research is required on customer behavior regarding sustainable leather products. Comprehending the determinants that affect consumers' purchasing choices about eco-friendly leather is essential for enhancing market demand for sustainable leather goods. Yadav et al. (2024) and Hira et al. (2020) emphasize the significance of examining consumer attitudes and behaviors, as these insights will enable firms to more effectively align their products with market demands and stimulate the demand for environmentally friendly alternatives.

Finally, the social implications of sustainable methods in the leather sector, especially regarding labor conditions and gender equality, have not been sufficiently examined. Mammadova et al. (2020) and Hira et al. (2020) assert that research must concentrate on elucidating how sustainable practices can enhance workers' rights, health, and safety, while concurrently tackling gender equality challenges within the leather sector.

The highlighted gaps indicate critical areas requiring additional research to facilitate the transition to a more sustainable leather production process in South Asia. By addressing these deficiencies, subsequent research can assist the sector in surmounting current obstacles and advancing towards more environmentally and socially responsible practices.

Table 4: Research gaps and propose future research directions

	Research Gaps	Propose Future Research Directions	Authors
1	Limited research on the economic viability of sustainable leather technologies, especially for small-scale producers.	Investigate cost-benefit analyses of sustainable technologies in leather production, focusing on financial barriers for SMEs (Small and Medium Enterprises).	Kanagaraj et al., 2020; Akbar et al., 2025
2	Insufficient research on scalable solutions for the widespread adoption of alternative tanning agents and waste management techniques.	Conduct studies to develop scalable, affordable technologies for alternative tanning and waste management to ensure industry-wide adoption.	
3	Lack of comprehensive studies on the integration of circular economy practices across the entire leather supply chain.	Explore how circular economy principles can be integrated seamlessly across the leather supply chain, from sourcing to end-of-life management.	Moktadir et al., 2020; Kanagaraj et al., 2020
4	Limited exploration of consumer behavior towards sustainable leather products and its impact on market demand.	Examine consumer perceptions and behavior regarding eco-friendly leather products and determine factors influencing purchasing decisions.	
5	Inadequate research on the social impacts of sustainable practices in the leather industry, particularly regarding labor conditions and gender equality.	Investigate the social dimensions of sustainable leather production, particularly the effects on workers' rights, gender equality, and local communities.	Mammadova et al., 2020; Hira et al., 2020

Implications of the Study

The research on sustainable leather production in South Asia provides critical insights into the industry's present condition and outlines a strategy for its future development. It elucidates the problems and opportunities that emerge from the shift towards more sustainable practices in this area. These implications are significant for academic researchers, industry practitioners, and policymakers seeking to expedite the adoption of sustainable technology and enhance the socio-economic and environmental effects of leather manufacturing.

Economic and Environmental Policy Implications

This study's findings underscore the essential importance of robust legislative frameworks in advancing sustainable leather production. South Asian nations, including India, Bangladesh, and Pakistan, require enhanced regulatory enforcement to guarantee that tanneries implement environmentally sustainable techniques. The research underscores the necessity of harmonizing national regulations with global sustainability benchmarks, including the EU REACH directive and the UN Sustainable Development Goals (SDGs). This alignment will be essential for maintaining the region's competitiveness in the global

market while also minimizing its environmental impact. Policymakers are urged to incorporate environmental and economic factors in forthcoming rules, guaranteeing that sustainability is both an ecological imperative and an economic essential.

Technological Innovation and Investment

This study underscores the necessity for significant investment in sustainable methods for leather production. The research demonstrates that although significant potential exists for innovations like alternative tanning agents, nanomaterials, and circular economy practices, their extensive implementation is obstructed by substantial initial costs and restricted access to financing, especially for small and medium-sized enterprises (SMEs). The research highlights the imperative for financial instruments, including green finance, to assist SMEs in adopting more sustainable production practices. Furthermore, there is a distinct necessity for additional technological advancements that reduce the expenses associated with sustainable practices, such as bio-based dyes and waste management solutions, to enhance the accessibility of these technologies throughout the sector.

Social and Labor Implications

This study underscores the importance of incorporating social sustainability into the environmental framework of the leather sector. The report emphasizes that the leather industry in South Asia is a major employer, frequently of marginalized populations, with numerous workers facing exposure to toxic chemicals and substandard working conditions. Advancing sustainability in the leather sector necessitates enhancing the social conditions of workers. Future study should concentrate on discovering effective techniques to enhance labor practices, promote gender equality, and improve overall worker safety, in conjunction with the implementation of green technologies. This would guarantee that the advantages of sustainable leather manufacturing are fairly allocated throughout the whole value chain.

Consumer Awareness and Market Demand

The transition to eco-friendly leather products depends on evolving consumer behavior. This study indicates an increasing demand for sustainable products, yet it remains a niche market. To broaden this market, heightened consumer awareness regarding the environmental repercussions of conventional leather production and the advantages of eco-friendly alternatives is essential. The study proposes that marketing strategies, coupled with clearer product labeling and certification systems, could bolster consumer trust and encourage the adoption of sustainable leather products. A concerted initiative to educate consumers about the benefits of products made from sustainable materials could profoundly impact market dynamics.

Finally, the study emphasizes the necessity of collaboration throughout the whole leather supply chain to attain sustainability. The disjointed structure of the supply chain poses a considerable obstacle to the adoption of sustainable practices. The research indicates that enhancing collaboration among stakeholders, including raw material suppliers, producers, and merchants, is crucial for establishing a sustainable and efficient leather production system. The exchange of knowledge, resources, and technical advancements can promote a unified strategy for sustainability, diminishing obstacles to the implementation of environmentally friendly activities and enhancing the overall effect.

This study has significant consequences for the future of the leather industry in South Asia. It offers essential insights for academic academics, industry professionals, and policymakers to collaborate in addressing difficulties and capitalizing on possibilities for a

more sustainable leather sector. The findings indicate that the future sustainability and economic viability of the leather industry in the region will depend on the integration of technical innovation, enhanced regulatory frameworks, improved labor conditions, and increased consumer awareness.

Limitations of the Study

While this bibliometric analysis provides valuable insights into the state of research on sustainable leather production in South Asia, it has several limitations. First, the study relies solely on data from the Scopus database, which may exclude relevant publications indexed in other databases, potentially limiting the comprehensiveness of the analysis. Second, bibliometric methods primarily focus on quantitative metrics such as publication counts and citation patterns, which may not fully capture the qualitative aspects and contextual nuances of research in this field. Third, the review period ending in 2024 may exclude the most recent developments and emerging trends that have yet to be extensively published or cited. Finally, the study concentrates on sustainability within South Asia, and findings may not be directly generalizable to other geographic regions with different industrial, regulatory, and socio-economic contexts. Future research could address these limitations by incorporating multi-database searches, qualitative content analysis, continuous monitoring of the field, and comparative studies across regions.

Conclusion

This paper presents a thorough bibliometric analysis of sustainable leather manufacturing in South Asia, emphasizing the industry's increasing significance along with the problems and opportunities associated with the adoption of more environmentally sustainable processes. The leather industry, vital to the economies of nations like India, Bangladesh, and Pakistan, is also among the most environmentally detrimental sectors. This study has examined how, despite the economic importance of the leather sector, it faces pressure to transition towards sustainability due to environmental and social issues.

The study's key findings reveal that, despite significant potential for innovation in sustainable leather production, the transition is hindered by elevated costs, insufficient technological progress, and disjointed supply chains. Moreover, insufficient infrastructure and inadequate enforcement of regulatory frameworks in South Asia have impeded the extensive adoption of environmentally sustainable technologies. The report emphasizes the necessity of enhanced legislative support, technological advancement, and international cooperation to promote the industry's transition to sustainability.

This study finds notable research deficiencies in the sector, namely concerning the economic viability of sustainable technology, the incorporation of circular economy techniques, and the social ramifications of sustainable manufacturing. Future research must concentrate on creating scalable solutions that reduce costs and enhance resource efficiency, while also tackling the social and economic aspects of sustainability, such as work conditions and customer behavior.

The results of this bibliometric review indicate that implementing sustainable practices in the leather sector is crucial for mitigating its environmental effect and securing its long-term sustainability. The study enhances the existing knowledge base by delivering significant insights for policymakers, researchers, and industry professionals, presenting a framework for future advancements in sustainable leather production. Progressing, the incorporation of environmentally friendly technologies, robust policies, and heightened

collaboration throughout the supply chain will be essential for promoting sustainability in the leather industry in South Asia.

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