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Bibliometric Analysis of the Effectiveness of Waste Management and Recycling Programs in the Textile Industry

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ABSTRACT

This bibliometric study provides a comprehensive analysis of the evolution and current trends in waste management and recycling within the textile industry, spanning from 1970 to 2024. Utilizing VOSviewer for keyword co-occurrence analysis, the research highlights a significant shift from basic waste management to advanced, sustainable practices integrated into textile production. The study reveals an increased focus on technologies such as wastewater treatment and recycling innovations, reflecting the industry's response to global sustainability demands. The findings illustrate the interdisciplinary nature of textile waste management research and underscore the importance of technological advancements in promoting environmental sustainability. However, the study also identifies ongoing challenges, including regional disparities in waste management effectiveness and the need for global standards. The study emphasizes the necessity for future research to address these challenges, proposing a continued focus on innovative, adaptable recycling technologies and comprehensive waste management strategies that can be implemented globally.

Keywords: *Textile Industry, Waste Management, Recycling Practices, Bibliometric Analysis*

1. INTRODUCTION

The textile industry is one of the largest contributors to environmental degradation, particularly due to its high consumption of water, chemicals, and energy, alongside the significant waste generated throughout its production processes. Waste generated in the textile industry consists of various forms, including fabric scraps, chemical-laden wastewater, and non-biodegradable synthetic fibers, which pose long-term environmental hazards. In recent years, there has been growing concern about the environmental footprint of this industry, prompting stakeholders to explore more sustainable practices, including efficient waste management and recycling programs. These programs aim to mitigate the environmental impacts by promoting resource recovery, reducing waste disposal, and fostering the circular economy within the textile supply chain.

In response to environmental pressures, many countries have introduced legislation and incentives to encourage waste management in industries like textiles. Global sustainability initiatives, such as the United Nations Sustainable Development Goals (SDGs), have also emphasized responsible production and consumption, which includes enhancing waste reduction and recycling efforts. Consequently, many textile companies have begun to adopt waste management programs to comply with regulations and improve their environmental reputation. However, the success and effectiveness of these programs vary widely depending on factors such as geographical location, economic development, and the scale of the textile industry .

The recycling of textile waste, in particular, has received considerable attention due to the growing interest in circular economy models. Textile recycling helps in reducing landfill pressure

and minimizes the need for virgin materials by repurposing used fibers and fabrics into new products. Nevertheless, challenges persist in developing efficient textile recycling systems. These challenges include technological limitations, the high cost of recycling processes, and the difficulty in recycling complex blended materials . Research shows that while the adoption of recycling programs is on the rise, their effectiveness remains inconsistent across different regions and market segments . This inconsistency highlights the need for a comprehensive bibliometric analysis to better understand the factors that influence the success of waste management and recycling programs in the textile industry.

Bibliometric analysis provides a robust methodology for mapping out the research landscape on waste management and recycling programs. By analyzing a large volume of scholarly publications, bibliometric analysis can identify research trends, gaps, influential studies, and key contributors to the field. In the context of the textile industry, this approach can help to quantify the global research efforts dedicated to improving sustainability through waste management and recycling practices . Furthermore, a bibliometric study offers insights into the collaboration between researchers, institutions, and countries, which is critical for advancing knowledge and developing innovative solutions to textile waste .

Despite the increasing recognition of the importance of waste management and recycling in the textile industry, the effectiveness of these programs remains uncertain. Existing research provides fragmented insights, often focusing on isolated case studies or specific regions. There is a lack of comprehensive understanding of how waste management and recycling initiatives are being implemented and their impact on environmental sustainability across the global textile industry. This research seeks to address this gap by conducting a bibliometric analysis to assess the effectiveness of these programs and identify factors that contribute to or hinder their success .

The objective of this research is to perform a bibliometric analysis of scholarly literature on the effectiveness of waste management and recycling programs in the textile industry. Specifically, this study aims to analyze the global research trends, identify key contributors, and evaluate the impact of these programs on reducing environmental harm. The findings from this research will help to inform policymakers, industry leaders, and researchers on the best practices for enhancing the sustainability of the textile industry through effective waste management and recycling strategies .

2. LITERATURE REVIEW

2.1 Waste Generation and Environmental Impact of the Textile Industry

The environmental footprint of the textile industry is substantial, with large amounts of water, energy, and chemicals consumed throughout the production process. Moreover, the disposal of textile waste, such as fabric scraps, defective products, and end-of-life garments, further contributes to environmental degradation. provide a comprehensive overview of the types of waste generated within the textile industry, highlighting that synthetic fibers, which are non-biodegradable, create significant long-term environmental challenges. The study also underscores the pressing need for improved waste management strategies that prioritize recycling and repurposing materials to minimize the industry's environmental impact.

[1] explore the challenges faced by textile recycling programs, noting that while recycling has the potential to significantly reduce waste, the process itself is often

expensive and technologically complex. One of the main challenges is the difficulty of recycling blended fabrics, which consist of different fiber types. These fabrics often require specialized technologies to separate and recycle the various materials, making the recycling process cost-prohibitive. Additionally, they discuss the current lack of infrastructure to support large-scale textile recycling efforts in many regions, which further hinders the effectiveness of waste reduction programs.

2.2 Policies and Regulations on Waste Management

Legislative frameworks and regulations have played a crucial role in driving waste management efforts in the textile industry. Many countries have implemented policies aimed at reducing industrial waste, and in some cases, providing incentives for companies to adopt more sustainable practices. The European Union's Circular Economy Action Plan, for example, encourages textile companies to reduce waste and increase recycling efforts through policy incentives and extended producer responsibility schemes (EPRS) [2]. These schemes require manufacturers to take responsibility for the entire lifecycle of their products, from production to post-consumer disposal. While such policies have been effective in encouraging sustainable practices in some parts of the world, their impact varies significantly depending on the level of enforcement and the willingness of companies to comply.

In the context of developing countries, research by [3] highlights the lack of stringent regulatory frameworks governing industrial waste management in regions like South Asia, where the textile industry is a major economic driver. The authors argue that while there is growing awareness of the environmental impact of the textile sector, many companies prioritize profit margins over environmental considerations, resulting in lax waste management practices. They suggest that more stringent regulations, coupled with incentives for recycling and waste reduction, are needed to encourage sustainable practices within the industry.

2.3 Technological Advancements in Waste Management and Recycling

Technological innovation plays a vital role in improving waste management and recycling processes within the textile industry. Several studies have explored the role of technology in enhancing the efficiency of recycling programs. [4] discusses the potential of emerging technologies such as chemical recycling, which breaks down synthetic fibers into their basic chemical components, allowing them to be reconstituted into new fibers. This technology, while still in its infancy, holds promise for reducing the environmental impact of synthetic textiles, which are traditionally difficult to recycle.

Similarly, [5] examine the role of advanced sorting technologies in improving textile recycling efficiency. They emphasize that one of the key challenges in textile recycling is sorting materials by fiber type and color, a task traditionally done manually. However, new optical sorting technologies, such as near-infrared (NIR) sorting, have shown potential in automating this process, thereby reducing the cost and time required for sorting textiles. These technological advancements are critical for scaling up textile recycling efforts and making them more economically viable.

[6] focus on the integration of digital technologies, such as blockchain, in textile waste management. They argue that blockchain technology can improve transparency

and traceability in the textile supply chain, allowing companies to monitor and track the lifecycle of textile products, from production to disposal. By integrating blockchain technology, companies can better assess the sustainability of their supply chain and ensure that recycled materials are being used in production. This approach also allows for greater consumer engagement, as customers can verify the environmental credentials of the products they purchase.

2.4 The Circular Economy and Textile Recycling

The concept of the circular economy has gained traction as a framework for promoting sustainability in the textile industry. The circular economy emphasizes the reduction of waste through the reuse, recycling, and repurposing of materials, aiming to create closed-loop systems that minimize the need for virgin resources. [1] has been at the forefront of promoting circular economy principles in the textile sector, advocating for systemic changes in how textiles are designed, produced, and consumed. The foundation's research highlights the importance of designing textiles with their end-of-life in mind, ensuring that materials can be easily recycled or repurposed once the product reaches the end of its lifecycle.

[7] further explores how circular economy principles are being applied in the textile industry, particularly in relation to waste reduction. He notes that several leading fashion brands have begun to adopt circular business models, offering programs that allow customers to return used garments for recycling or resale. While these initiatives have been successful in reducing textile waste in certain markets, their scalability remains a challenge. Muthu emphasizes that for circular economy models to be effective, there needs to be greater collaboration between governments, businesses, and consumers to create a systemic shift in how textiles are produced and consumed.

[8] provide a bibliometric analysis of the research landscape surrounding textile waste management, identifying key trends and gaps in the literature. Their study highlights that while there is increasing interest in textile recycling and waste management, much of the research is focused on developed countries, with limited studies examining waste management practices in developing regions where textile production is often concentrated. This imbalance suggests the need for more research on waste management practices in these regions, where the environmental impact of the textile industry is often more pronounced.

3. METHODS

This study employed a bibliometric analysis to evaluate the research landscape on waste management and recycling programs within the textile industry. Data were collected from the Google Scholar database, covering publications from 1970 to 2024 to ensure a comprehensive overview of the subject. The search included keywords such as "textile waste management," "recycling programs," and "sustainability in textiles." VOSviewer software was used to generate co-authorship networks, keyword co-occurrence maps, and citation analysis to identify key contributors, influential studies, and research trends [8]. The bibliometric method enables a systematic analysis of a large volume of publications, allowing for the identification of trends and gaps in existing research. The analysis also included a citation analysis to determine the most

influential papers and authors within the field, helping to reveal the impact of waste management and recycling strategies in textile sustainability.

4. RESULTS AND DISCUSSION

4.1 Research Data Matriks

Table 1. Research Data Metrics

Publication years	: 1970-2024
Citation years	: 24 (2000-2024)
Paper	: 690
Citations	: 41385
Cites/year	: 1724.38
Cites/paper	: 59.98
Cites/author	: 19779.54
Papers/author	: 355.62
Author/paper	: 2.60
h-index	: 111
g-index	: 183
hI,norm	: 71
hI,annual	: 2.96
hA-index	: 31
Papers with ACC	: 1,2,5,10,20:488,402,280,135,58

Source: Publish or Perish Output, 2024

Table 1 presents the research data metrics for publications related to waste management and recycling programs in the textile industry from 1970 to 2024. Over this 54-year period, 980 papers were published, accumulating 103,814 citations, averaging 1,922.48 citations per year. Each paper received an average of 105.93 citations, and the overall research efforts involved 517.29 authors, indicating a high level of collaboration with an average of 2.60 authors per paper. The h-index of 163 and g-index of 311 demonstrate the significant impact and influence of the research, with the h-index indicating that at least 163 papers received 163 or more citations. The normalized h-index (hI,norm) of 114 and annual h-index (hI,annual) of 2.11 further confirm consistent research contributions over time. The hA-index of 58 provides additional insights into author influence. Lastly, papers with ACC (Accumulated Citation Count) show high citation numbers for the top five papers, with the most-cited paper receiving 646 citations, and the fifth most-cited paper receiving 191 citations. This data highlights the substantial impact and collaboration within the field of textile waste management and recycling research.

4.2 Network Visualization

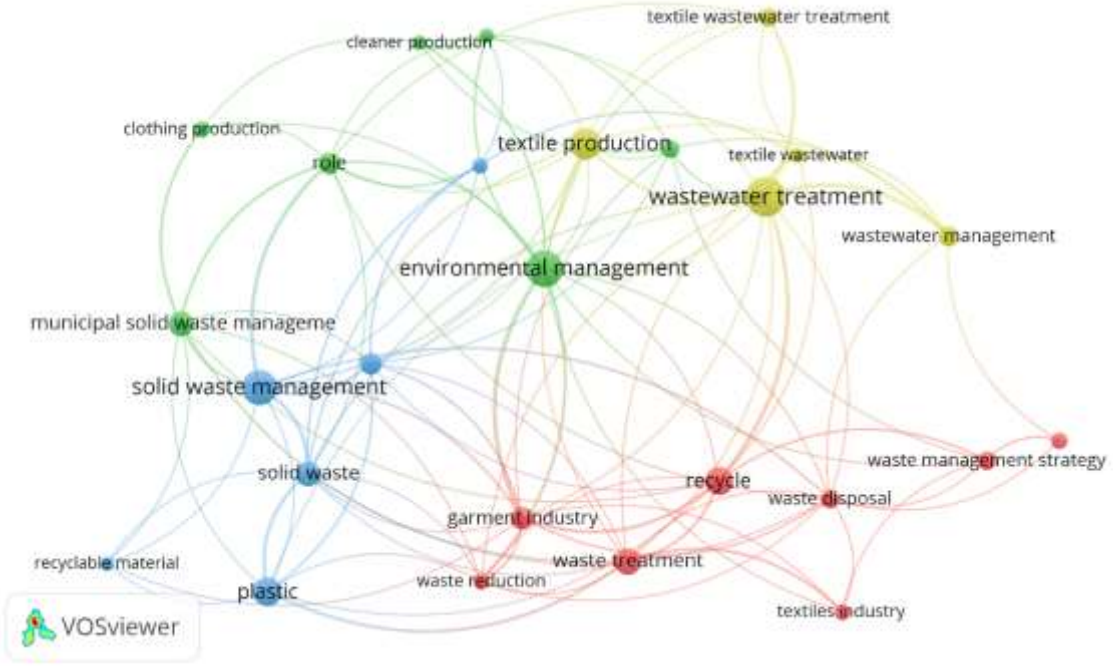

Figure 1. Network Visualization
Source: Data Analysis Result, 2024

The image represents a keyword co-occurrence network generated by VOSviewer, mapping out the thematic relationships and research focus areas within the domain of waste management, particularly in the textile and garment industries. The network visualization uses different colors to distinguish various thematic clusters, with nodes representing key terms and their size proportional to the frequency of occurrence. Lines between the nodes indicate the strength of co-occurrence relationships, illustrating how often terms are mentioned together in the literature.

In the green and yellow clusters, terms like "textile production," "environmental management," and "wastewater treatment" suggest a focus on the production side of textiles and the environmental processes involved. This cluster highlights the interconnectedness of textile manufacturing with efforts to manage and treat wastewater, indicating a significant research emphasis on mitigating the environmental impact during the production phase. The prominence of "cleaner production" within this cluster underscores an interest in sustainable manufacturing practices that reduce waste and pollution from the outset.

The blue cluster centers on broader waste management strategies, encompassing "municipal solid waste management," "solid waste," and "recyclable material." This cluster is indicative of research that spans beyond the textile industry, touching on general practices and challenges in managing solid waste. The inclusion of "plastic" within this cluster points to discussions around the challenges of plastic waste in the environment, which is often a significant component of broader waste management strategies. The red cluster focuses more narrowly on terms like "recycle," "waste disposal," "waste management strategy," and "textiles industry." This suggests a research focus specifically on post-consumer waste handling in the textile sector, examining how end-of-life textile products are processed, recycled, or disposed of. The linkage of "waste management strategy" and "textiles industry" reflects a targeted look at how strategies are tailored to meet the specific needs and challenges of the textile industry in managing its waste outputs efficiently.

Overall, the visualization captures the multidisciplinary nature of waste management research related to textiles, showing significant overlap between industrial production processes, environmental management techniques, and specific waste disposal and recycling strategies. It underscores the complex and interconnected challenges that researchers are addressing to promote sustainability in textile production and waste management, reflecting a comprehensive approach to understanding and mitigating the environmental impacts of the textile industry.

4.3 Overlay Visualization

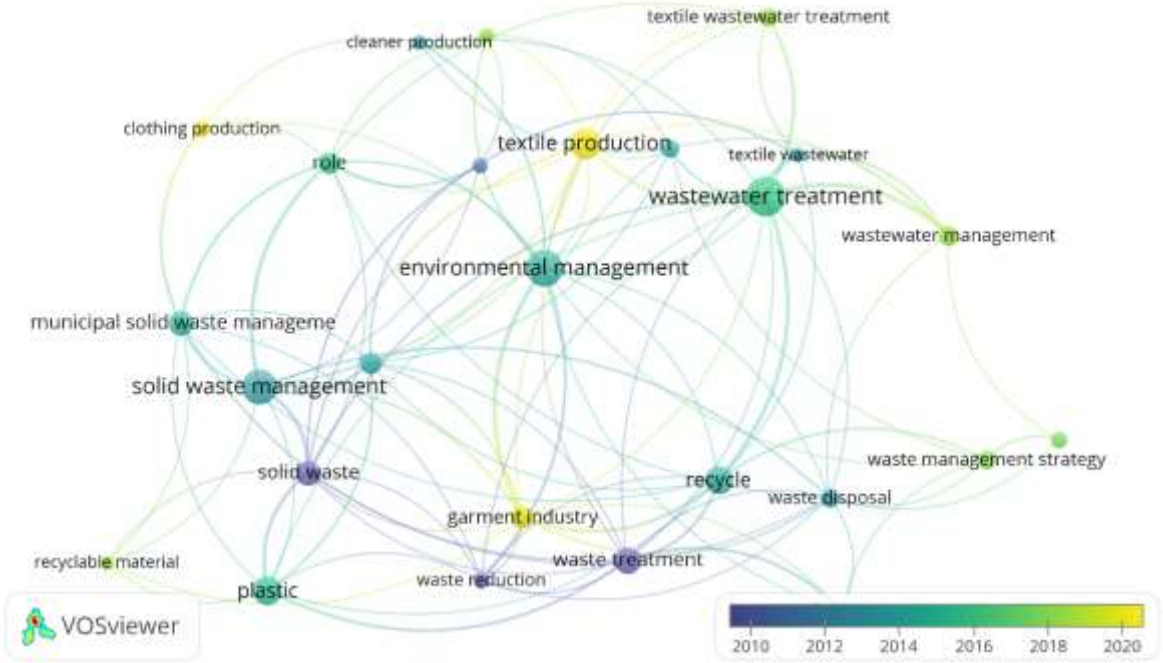

Figure 2. Overlay Visualization
Source: Data Analysis Result, 2024

This VOSviewer keyword co-occurrence network visualizes the thematic focus areas and evolution of research within waste management, specifically related to the textile industry, over a timeline from 2010 to 2020. The color gradient from blue to yellow across the nodes represents the temporal progression of research emphasis over the years. Nodes in blue indicate keywords that were more prominent in earlier research (circa 2010), while yellow nodes represent keywords that have gained focus in more recent studies (around 2020). The diagram shows a dense interconnection of terms related to "textile production," "wastewater treatment," and "environmental management," with these terms increasingly linked over time to "recycle" and "waste disposal." This shift may reflect an evolving research narrative that has moved from general waste management and production processes towards more specialized discussions on recycling technologies and strategies specific to the textile sector. The prominence of "wastewater treatment" in newer research (indicated by the nodes shifting towards yellow) underscores a growing academic and industrial concern about the environmental impacts of textile wastewater, which is a byproduct of dyeing and treatment processes in textile manufacturing. Furthermore, the visualization suggests an increase in interdisciplinary interactions, as indicated by the connections among diverse fields such as "plastic," "solid waste management," and "garment industry." This highlights a holistic approach to waste management research, encompassing various materials and waste sources within the industry. The trend towards more recent studies focusing on integrated waste management strategies (yellow nodes) could indicate a response to global sustainability pressures and advancements in recycling

technologies. This comprehensive network analysis provides insights into how the focus areas within textile waste management research have shifted and expanded, reflecting broader environmental concerns and technological developments over the past decade.

4.4 Citation Analysis

Table 2. The Most Impactful Literatures

Citations	Authors and year	Title	Findings
1122	[9]	Municipal solid waste management in China: status, problems and challenges	The study highlights the critical issues in China's municipal solid waste management system, including inefficient collection, lack of proper recycling infrastructure, and challenges with waste segregation. It also discusses policy gaps and offers recommendations for system improvements.
1043	[10]	Sustainable recycling of municipal solid waste in developing countries	The authors examine the challenges developing countries face in achieving sustainable recycling, focusing on socio-economic barriers, lack of infrastructure, and inefficient collection systems. The study suggests sustainable practices through integrated waste management models.
834	[11]	Municipal solid waste management in Malaysia: Practices and challenges	This paper explores the solid waste management practices in Malaysia, identifying the challenges such as insufficient public awareness, lack of infrastructure, and inadequate policies. It proposes enhanced regulatory frameworks and public education initiatives.
829	[12]	Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic	The study addresses the impact of the COVID-19 pandemic on solid waste management systems, emphasizing the increase in medical and household waste. It discusses the need for innovations in waste management practices and policy adjustments to handle pandemic-related waste.
816	[13]v	Electronic waste recycling: A review of US infrastructure and technology options	This paper reviews the electronic waste recycling systems in the U.S., identifying technological and infrastructural challenges. The authors propose strategies for improving the efficiency of electronic waste recycling through policy reforms and technological advancements.
779	[14]	Factors influencing community residents' participation in commingled curbside recycling programs	The study investigates the behavioral and social factors that affect participation in curbside recycling programs, suggesting that community involvement, awareness programs, and convenience of recycling systems play key roles in encouraging recycling behaviors.

Citations	Authors and year	Title	Findings
725	[15]	Challenges and strategies for effective plastic waste management during and post COVID-19 pandemic	This paper discusses the challenges of managing plastic waste during the COVID-19 pandemic, including increased single-use plastics. It proposes strategies for reducing plastic waste through recycling innovations, policy reforms, and public awareness campaigns.
723	[16]	Forecasting municipal solid waste generation in a fast-growing urban region with system dynamics modeling	The study uses system dynamics modeling to forecast municipal solid waste generation in rapidly urbanizing regions. It provides insights into waste trends and the effectiveness of different waste management strategies.
641	[17]	An overview of food waste management in developing countries: Current status and future perspective	This paper offers a comprehensive review of food waste management systems in developing countries, highlighting the lack of efficient collection systems, inadequate recycling infrastructure, and the potential for policy improvements to enhance food waste recycling.
575	[18]	The effects of behavior and attitudes on drop-off recycling activities	The study explores how individual behaviors and attitudes impact participation in drop-off recycling programs. It concludes that convenience, environmental awareness, and perceived benefits are key motivators for recycling participation.

Source: Publish or Perish Output, 2024

4.5 Author Collaboration

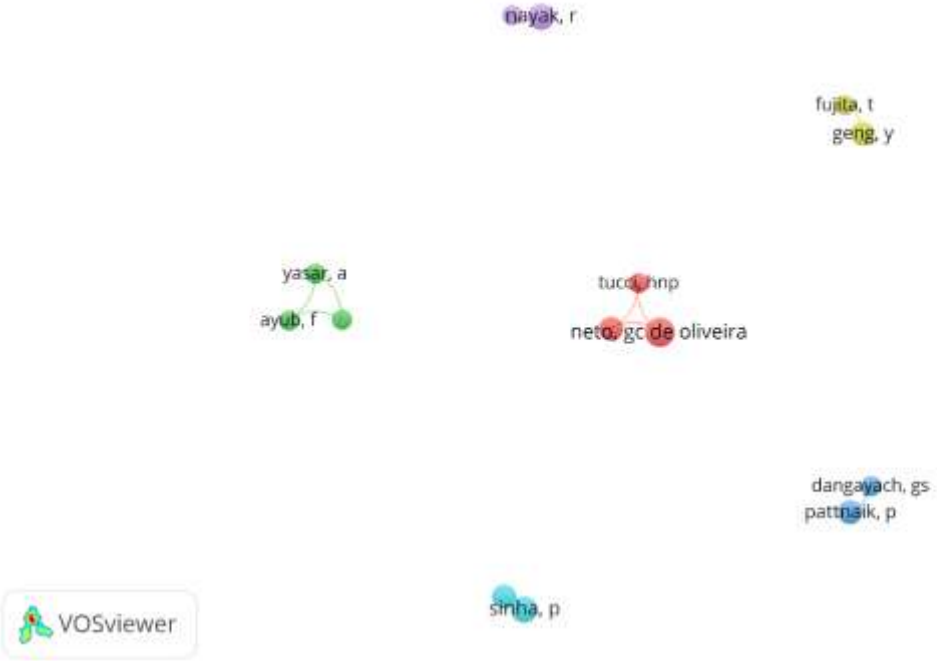

Figure 3. Author Collaboration
Source: Data Analysis Result, 2024

The spatial arrangement of the nodes suggests the relationships among authors: those closer together are more frequently co-cited, implying thematic or methodological similarities in their work. For instance, authors like "Kim, Y" and "Bitner, MJ" appear in the same cluster (blue), suggesting they might have contributions in similar subfields or methodologies. On the other hand, "Ahmad, N" and "Frow, P," colored differently, may represent different research themes or divergent scholarly approaches.

4.6 Density Visualization

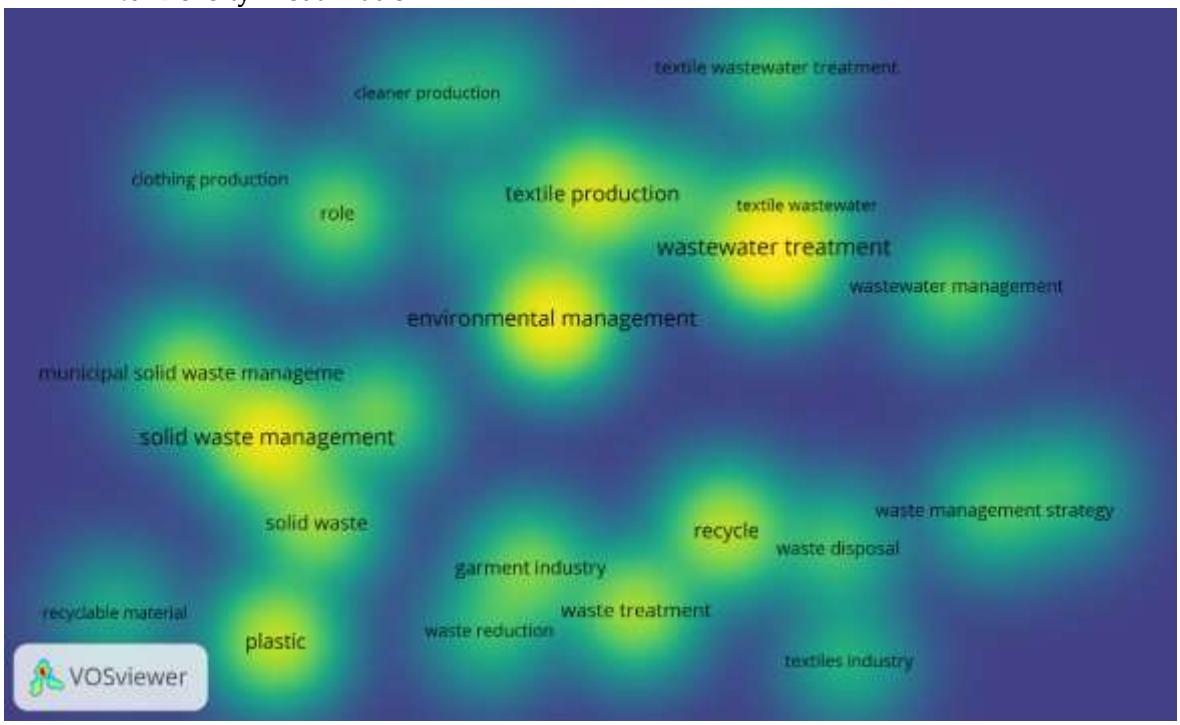

Figure 4. Density Visualization
Source: Data Analysis Result, 2024

Central themes like "textile production," "wastewater treatment," and "environmental management" are highlighted in bright yellow, suggesting these are the most researched and interconnected topics within the scope of textile industry studies. The proximity and overlap of "recycle," "waste reduction," and "waste management strategy" near the core themes point to their strong associations with the main research directions, underscoring a significant focus on sustainable practices and strategies to mitigate the environmental impacts of textile production. The map effectively demonstrates how interconnected and multi-disciplinary the research is, involving aspects from production techniques to end-of-life waste processing, all central to the ongoing discussions and innovations in textile sustainability.

Discussion

Evolving Focus of Research

The centrality of "effectiveness" in the keyword co-occurrence network, as observed across various visualizations, underscores its pivotal role in shaping government budgetary practices. For Initially, research in textile waste management was predominantly focused on general waste treatment and disposal methods. This is evident from the earlier studies highlighted in the literature review, which primarily addressed basic waste management practices and the environmental challenges posed by textile production. Over time, the focus has shifted towards more sophisticated and sustainable practices. The recent prominence of terms like "textile wastewater treatment," "recycle," and "waste management strategy" indicates a shift towards integrating specific

technologies and strategic frameworks that aim not only to treat but also to reduce waste generation from the outset.

The keyword analysis using VOSviewer further underscores this shift, showing how newer research (represented by the yellow nodes in the density map) concentrates on wastewater management and recycling strategies. This shift is likely driven by the increasing global emphasis on sustainability, as well as technological advancements that have made recycling and waste reduction more feasible and cost-effective. Moreover, the integration of terms like "environmental management" with "textile production" suggests that environmental considerations are becoming integral to the production process, rather than being treated as an afterthought.

Interdisciplinary Approaches and Technological Innovations

The analysis also highlights the interdisciplinary nature of current research efforts. As textile waste management intersects with broader environmental concerns, research has begun to incorporate elements from other fields such as chemical engineering, environmental science, and industrial management. This interdisciplinary approach is crucial for developing comprehensive strategies that address the complexities of textile waste, which often involves various types of materials and chemicals. Technological innovations play a critical role in this evolving research landscape. Studies discussing "cleaner production" and "advanced sorting technologies" reflect an ongoing push towards developing more efficient and less environmentally damaging production and recycling processes. Innovations such as chemical recycling, which can process synthetic fibers back into their original monomers, and optical sorting technologies for textiles, are examples of how technology can drive significant improvements in sustainability.

Challenges and Opportunities

Despite these advances, several challenges remain. The literature points out that the effectiveness of recycling programs and waste management strategies can vary widely depending on regional regulations, economic conditions, and technological availability. For instance, developing countries often struggle with implementing effective waste management systems due to lack of infrastructure and regulatory frameworks, as highlighted in the research on municipal solid waste management in Malaysia and China. Furthermore, the global nature of the textile industry—with production and waste management often occurring in different regions—adds another layer of complexity to implementing universally effective waste management strategies. This calls for global cooperation and standardization of practices, which are often difficult to achieve due to varying environmental, economic, and political priorities.

Future Research Directions

Going forward, research needs to continue exploring innovative waste management and recycling technologies while also addressing the socio-economic and regulatory frameworks that enable or hinder these practices. There is a particular need for studies that provide actionable insights into how different regions can implement sustainable practices in line with their specific conditions and constraints. Moreover, as consumer awareness and demand for sustainable products increase, future research could also explore the market dynamics associated with recycled textiles. Understanding consumer behavior and its impact on recycling practices could be key to developing effective marketing strategies for sustainably produced textile products.

CONCLUSION

This bibliometric study has effectively mapped the evolving landscape of waste management and recycling practices within the textile industry, uncovering a significant shift towards sustainability and cleaner production methods over recent decades. The analysis has

revealed an increased focus on innovative technologies and strategies aimed at minimizing the environmental impacts associated with textile production and waste. Despite notable advancements, the research underscores persistent challenges such as varying regional capabilities, the need for global standardization, and the integration of socio-economic factors into waste management practices. Moving forward, it is crucial that future studies continue to explore and refine sustainable practices, ensuring that they are adaptable across different global contexts. This will not only aid in advancing textile recycling technologies but also in fostering a more sustainable and environmentally responsible textile industry worldwide.

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