

Socio-Technological Transitions in Agriculture: A Bibliometric and Systematic Analysis of Global Trends and Future Directions

Hariyanti Hamid^{1)*}, Suparman Abdullah²⁾, Rahmat Muhammad²⁾, Herman Dema¹⁾

¹⁾ Faculty of Social and Political Science, Universitas Muhammadiyah Sidenreng Rappang, Jl. Angkatan 45 No. 1A, Sidenreng Rappang, 91651, Indonesia

²⁾ Faculty of Science and Political Science, Hasanuddin University, Jl. Perintis Kemerdekaan Km. 10, Makassar, 90245, Indonesia

*Corresponding author: hariyantiamid2169@gmail.com

Submitted: 21 June 2026 | Accepted: 24 Juni 2026 | Published: 25 Juni 2026

Abstract

The agricultural sector is undergoing rapid transformation driven by digital innovation, climate change, sustainability challenges, and increasing food security demands. Understanding how technological innovation interacts with social and institutional change has become essential for supporting sustainable agricultural development. This study aims to examine the evolution of socio-technical transition research in agriculture through an integrated bibliometric analysis and systematic literature review approach. Data were collected from the Scopus database, resulting in a final dataset of 777 publications published between 2020 and 2024. Bibliometric analysis was conducted using VOSviewer to identify publication trends, collaboration networks, conceptual structures, and intellectual foundations of the field. The results indicate a substantial increase in scientific publications, rising from 53 documents in 2020 to 157 documents in 2024, reflecting growing global interest in agricultural transformation. China and the United States emerged as the leading contributors to scientific production, while increasing participation from developing countries highlights the global relevance of socio-technical transitions. Keyword co-occurrence analysis revealed dominant themes related to digital agriculture, technology adoption, sustainability, climate adaptation, social inclusion, and agricultural innovation systems. Co-citation analysis demonstrated strong intellectual connections among digital farming, sustainability transition, and innovation studies. The findings highlight a shift from technology-centered perspectives toward more integrated approaches emphasizing governance, institutional support, and equitable access to innovation. This study provides a comprehensive knowledge map and identifies future research directions for promoting inclusive and sustainable agricultural transitions.

Keywords: Socio-Technical Transitions; Digital Agriculture; Agricultural Innovation; Bibliometric Analysis; Sustainability Transition

1. Introduction

Over the past two decades, the global agricultural sector has encountered unprecedented challenges related to food security, climate change, environmental degradation, resource scarcity, and increasing sustainability imperatives. The growing global population, coupled with rising demand for food, has intensified pressure on agricultural systems to increase productivity while simultaneously reducing environmental impacts and enhancing resilience. Traditional agricultural practices are increasingly perceived as insufficient to address these complex and interconnected challenges, thereby necessitating transformative changes in agricultural production systems, governance structures, and rural livelihoods. Consequently, agricultural development is no longer viewed solely as a process of technological improvement but rather as a multidimensional transformation involving technological, social, economic, and institutional dimensions.

In response to these challenges, the rapid advancement of digital technologies has emerged as a key driver of agricultural transformation. Technologies such as the Internet of Things (IoT), artificial

intelligence (AI), big data analytics, unmanned aerial vehicles (UAVs), blockchain, remote sensing, and precision agriculture have reshaped agricultural production, resource management, and decision-making processes. These innovations have enhanced operational efficiency, improved productivity, and enabled more data-driven and sustainable farming practices. However, technological innovation alone does not guarantee successful transformation. The implementation and diffusion of agricultural technologies are deeply embedded within social contexts, institutional arrangements, policy environments, and stakeholder interactions. Therefore, agricultural transformation increasingly reflects a broader socio-technical transition process in which technological innovations co-evolve with social practices, organizational structures, governance systems, and institutional change.

The concept of socio-technical transitions has gained considerable attention within sustainability transition studies, particularly through perspectives such as the Multi-Level Perspective (MLP), transition management, and innovation systems theory. Within this framework, transitions are understood as long-term processes involving interactions among technological developments, societal actors, institutions, and broader environmental pressures. In the agricultural sector, socio-technical transitions encompass not only the adoption of digital technologies but also changes in farmers' knowledge, behavioral patterns, social networks, market relationships, policy frameworks, and institutional support mechanisms. Recent evidence from Indonesia indicates that ICT-based advisory services significantly enhance farmers' capacity, which subsequently strengthens agricultural resilience, highlighting the importance of capacity development as a mediating mechanism in technology-enabled agricultural transformation (Mursalat et al., 2026). Such transitions are particularly important in addressing sustainability challenges because they facilitate the integration of technological innovation with social learning, collective action, and institutional adaptation.

Despite the growing importance of socio-technical transitions in agriculture, the existing body of literature remains fragmented and dispersed across multiple disciplines, including agricultural sciences, rural sociology, innovation studies, sustainability science, information systems, and development studies. Most studies focus primarily on specific technological innovations, such as precision agriculture, smart farming, digital advisory services, or agricultural automation, while others emphasize social dimensions such as farmer behavior, knowledge exchange, institutional development, or rural transformation. As a result, limited attention has been devoted to understanding the broader intellectual structure and thematic evolution of socio-technical transition research in agriculture. Moreover, the interdisciplinary nature of the field has led to conceptual fragmentation, making it difficult to identify dominant research themes, emerging topics, collaborative networks, and future research directions.

Several review studies have examined topics related to digital agriculture, smart farming, agricultural innovation systems, and technology adoption. However, these reviews generally focus on specific technologies, geographical contexts, or disciplinary perspectives. To date, there remains a lack of comprehensive studies that systematically map the global development of socio-technical transition research in agriculture by integrating bibliometric analysis with systematic literature review approaches. Consequently, there is limited understanding of how the field has evolved over time, which actors and institutions contribute most significantly to knowledge production, what thematic clusters dominate the literature, and which emerging research areas deserve greater scholarly attention. Addressing these gaps is essential for advancing theoretical development and informing future interdisciplinary research agendas.

To address this limitation, the present study employs a combined Bibliometric Analysis and Systematic Literature Review (SLR) approach to provide a comprehensive assessment of global research on socio-technical transitions in agriculture. Bibliometric analysis enables the identification of publication trends, influential authors, leading institutions, scientific collaboration networks, and thematic structures within the literature. Meanwhile, systematic literature review facilitates a deeper examination of conceptual frameworks, methodological approaches, empirical findings, and emerging research directions. The integration of these two approaches allows for a more holistic understanding of the evolution and current state of knowledge in this field.

Specifically, this study aims to: (1) analyze global publication trends and scientific collaboration patterns related to socio-technical transitions in agriculture; (2) identify dominant research themes, intellectual structures, and emerging topics within the literature; (3) examine how socio-technical

transition concepts have been applied conceptually and empirically in agricultural contexts; and (4) propose future research directions to support sustainable agricultural transformation in the digital era.

Accordingly, this study addresses the following research questions: RQ1. How have publication trends and scientific collaboration patterns in socio-technical transition research within agriculture evolved globally? RQ2. What are the dominant thematic areas, intellectual structures, and emerging research trends in the field? RQ3. How has the concept of socio-technical transitions been applied conceptually and empirically in agricultural research? RQ4. What research gaps remain, and what future research directions can advance knowledge on socio-technical transitions in agriculture?.

By answering these questions, this study contributes to the literature in three important ways. First, it provides a comprehensive mapping of the intellectual landscape of socio-technical transition research in agriculture. Second, it identifies emerging themes and research gaps that can guide future scholarly inquiry. Third, it develops an interdisciplinary research agenda that integrates technological innovation, social transformation, and institutional change as interconnected components of sustainable agricultural development. The findings are expected to serve as valuable references for researchers, policymakers, development practitioners, and agricultural stakeholders seeking to understand and promote sustainable agricultural transitions in an increasingly digitalized world.

2. Research Methodology

2.1 Research Design

This study adopted an integrated bibliometric analysis and systematic literature review (SLR) approach to provide a comprehensive understanding of socio-technical transitions in agriculture. The integration of these methods enables the identification of publication trends, intellectual structures, collaboration networks, thematic developments, and conceptual insights within the field. Bibliometric analysis quantitatively maps the scientific landscape of research, whereas the systematic literature review provides a qualitative synthesis of theoretical perspectives, methodological approaches, and empirical findings. The combination of these methods offers a robust framework for understanding the evolution of knowledge and identifying future research directions in the field of socio-technical transitions in agriculture.

2.2 Data Collection and Search Strategy

The bibliometric dataset was obtained from the Scopus database, which was selected due to its extensive coverage of peer-reviewed scientific publications and its widespread use in bibliometric studies. Scopus provides comprehensive metadata, including citation information, author affiliations, keywords, and abstracts, making it suitable for mapping scientific knowledge structures and collaboration networks. The literature search was conducted in January 2026 using the following search query: TITLE-ABS-KEY (("socio-technical transition*" OR "sociotechnical transition*" OR "digital transformation" OR "technology adoption") AND (agricultur* OR farming OR "food system*")).

The search was restricted to publications published between 2020 and 2024, a period characterized by the rapid expansion of digital agriculture, smart farming technologies, and sustainability-oriented agricultural innovations. Only peer-reviewed journal articles and conference papers published in English were included in the dataset.

2.3 Study Selection Process

The study selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure transparency, reproducibility, and methodological rigor. The selection procedure consisted of four stages: identification, screening, eligibility assessment, and inclusion.

As illustrated in Figure 1, a total of 2,087 records were initially identified from the Scopus database. No duplicate records or automatically excluded documents were detected during the identification stage. Consequently, all retrieved records proceeded to the screening phase. The records were screened based on their titles, abstracts, and keywords to determine their relevance to socio-technical transitions in agriculture.

Subsequently, the screened documents underwent a full-text eligibility assessment. During this stage, publications that did not meet the predefined inclusion criteria were excluded. The exclusion process considered several factors, including publication year, document type, language, and topical relevance to socio-technical transitions within agricultural systems. Studies published outside the selected period (2020–2024), non-peer-reviewed publications, and studies lacking direct relevance to agricultural technological and social transformation were removed from the dataset. The complete study selection process is presented in Figure 1.

As shown in Figure 1, the application of the inclusion and exclusion criteria resulted in a final dataset of 777 eligible publications for further analysis. These studies formed the basis for the bibliometric analysis and systematic literature review. Among the selected publications, 493 studies were available through open-access sources, while the remainder were accessible through subscription-based databases. The final dataset provides a comprehensive representation of contemporary research on socio-technical transitions in agriculture and serves as a reliable foundation for mapping research trends, collaboration networks, thematic developments, and future research directions.

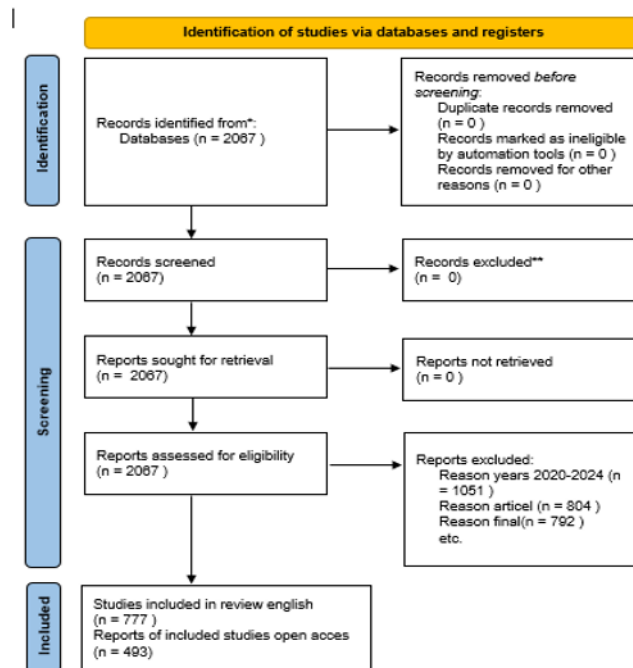


Figure 1. PRISMA 2020 Flow Diagram of the Literature Selection Process

2.4 Inclusion and Exclusion Criteria

To ensure the relevance and quality of the selected studies, a set of inclusion and exclusion criteria was established, as presented in Table 1.

Table 1. Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Language	English	Non-English publications
Publication Type	Journal articles and conference papers	Editorials, notes, book reviews, letters, books, and chapters
Publication Period	2020–2024	Publications before 2020
Subject Area	Agriculture, farming systems, food systems, digital agriculture, socio-technical transitions	Non-agricultural studies
Relevance	Studies discussing technological innovation, digital transformation, adoption, or socio-technical change in agriculture	Studies without direct relevance to agricultural transformation
Quality	Peer-reviewed publications	Non-peer-reviewed documents

The inclusion criteria ensured that the selected publications were directly related to the interaction between technological innovation and social transformation within agricultural systems. Publications that lacked conceptual or empirical relevance to socio-technical transitions were excluded from further analysis.

2.5 Bibliometric Analysis

Bibliometric analysis was conducted using VOSviewer version 1.6.20 to visualize and analyze scientific knowledge networks. VOSviewer was selected because of its capability to construct and display large bibliometric maps based on co-authorship, co-occurrence, citation, and co-citation relationships. Several bibliometric techniques were employed:

- Keyword co-occurrence analysis to identify dominant and emerging research themes.
- Co-authorship analysis to examine collaboration patterns among researchers, institutions, and countries.
- Citation analysis to identify influential publications and leading contributors.
- Co-citation analysis to reveal the intellectual foundations of the research field.
- Geographic distribution analysis to identify countries contributing significantly to socio-technical transition research in agriculture.

The analysis used a full-counting method and established minimum occurrence thresholds to ensure the robustness of network visualization. The resulting bibliometric maps were interpreted based on cluster formation, link strength, and node centrality, providing insights into the thematic structure and evolution of the field.

2.6 Systematic Literature Review

To complement the bibliometric findings, a systematic literature review was conducted on the selected studies. The review focused on synthesizing conceptual frameworks, methodological approaches, empirical evidence, and research gaps related to socio-technical transitions in agriculture.

The selected studies were analyzed using thematic coding and content analysis techniques. Particular attention was given to how technological innovations interact with social transformation, institutional change, governance mechanisms, farmer behavior, knowledge exchange, and sustainability outcomes. Through this process, the study identified key research themes, emerging issues, and future research opportunities that can contribute to the advancement of sustainable agricultural transformation.

The integration of bibliometric analysis and systematic literature review provides a comprehensive understanding of the development, current state, and future direction of socio-technical transition research in agriculture. This combined approach strengthens the reliability of the findings by linking quantitative mapping of scientific production with qualitative interpretation of the literature.

3. Results and Discussion

3.1 Study Selection Process

The study selection process followed the PRISMA 2020 guidelines to ensure transparency and methodological rigor in identifying relevant publications. As presented in Figure 2, a total of 2,087 records were initially retrieved from the Scopus database using predefined search terms related to socio-technical transitions in agriculture. The retrieved documents were screened according to publication period, document type, language, and thematic relevance.

Studies that did not meet the inclusion criteria were excluded during the screening and eligibility assessment stages. The final screening process resulted in 777 eligible publications, which were subsequently analyzed through bibliometric and systematic review approaches. The final dataset provides a comprehensive representation of contemporary research on socio-technical transitions in

agriculture and serves as the basis for identifying publication trends, collaboration patterns, conceptual structures, and intellectual foundations of the field.

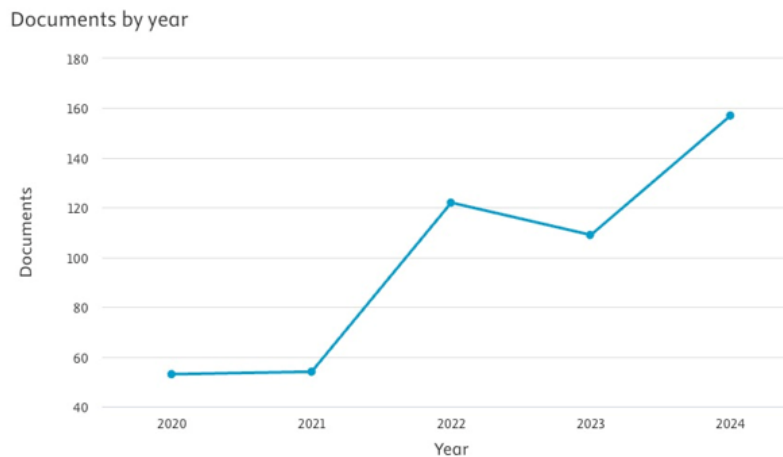


Figure 2. PRISMA 2020 Flow Diagram of the Literature Selection Process

3.2 Publication Trends in Socio-Technical Transition Research

The annual publication trend is presented in Figure 3. The results indicate a substantial increase in scientific publications related to socio-technical transitions in agriculture during the period 2020–2024. The number of publications increased from 53 documents in 2020 to 157 documents in 2024, representing nearly a threefold increase within five years.

A notable surge occurred between 2021 and 2022, when publications increased from 55 to 122 documents. This growth coincides with the acceleration of digital transformation in agriculture, driven by advances in artificial intelligence, Internet of Things (IoT) technologies, precision agriculture, and data-driven farm management systems. The COVID-19 pandemic further highlighted the importance of digital solutions in maintaining agricultural productivity and supply-chain resilience, stimulating increased academic interest in technology-enabled agricultural transformation.

Although a slight decline was observed in 2023, publication output rebounded strongly in 2024, reaching its highest level during the study period. This pattern suggests that socio-technical transitions have become an increasingly important research domain within agricultural sustainability studies. The growing publication trend also reflects a broader recognition that agricultural transformation requires not only technological innovation but also institutional adaptation, social learning, and stakeholder engagement.

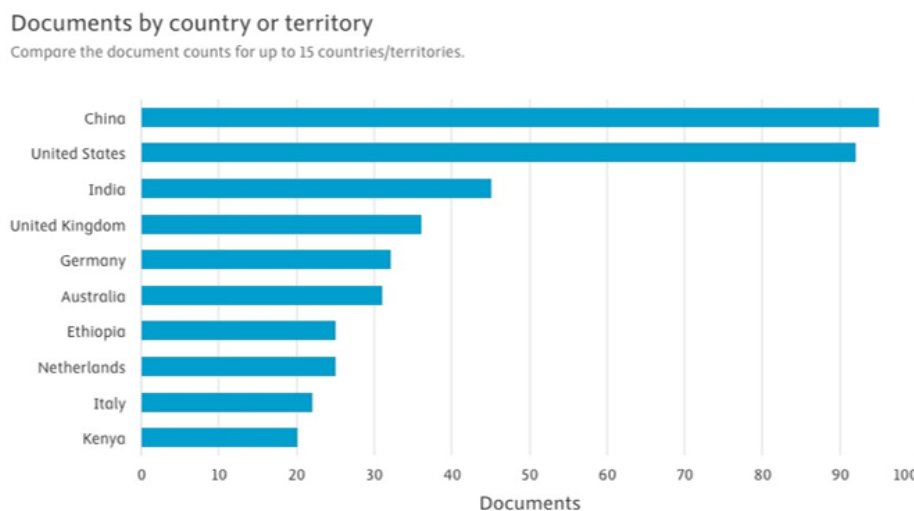


Figure 3. Annual Publication Trends in Socio-Technical Transition Research (2020–2024)

3.3 Geographic Distribution of Research

Figure 4 illustrates the geographical distribution of scientific publications. China emerged as the leading contributor with 95 publications, followed closely by the United States with 92 publications. India ranked third with 45 publications, while the United Kingdom, Germany, and Australia also demonstrated substantial contributions.

The dominance of China and the United States reflects their significant investments in agricultural innovation, digital infrastructure, and research and development programs. Both countries have actively promoted smart farming technologies, agricultural digitalization, and sustainable innovation systems, creating favorable conditions for scientific research and knowledge production.

Interestingly, several developing countries, including India, Ethiopia, and Kenya, also appeared among the leading contributors. This finding indicates that socio-technical transitions are not exclusively associated with developed economies but are increasingly viewed as critical mechanisms for addressing agricultural productivity, food security, and climate adaptation challenges in developing regions. The participation of African and South Asian countries highlights the growing importance of inclusive innovation and context-specific technological solutions within global agricultural transformation efforts.

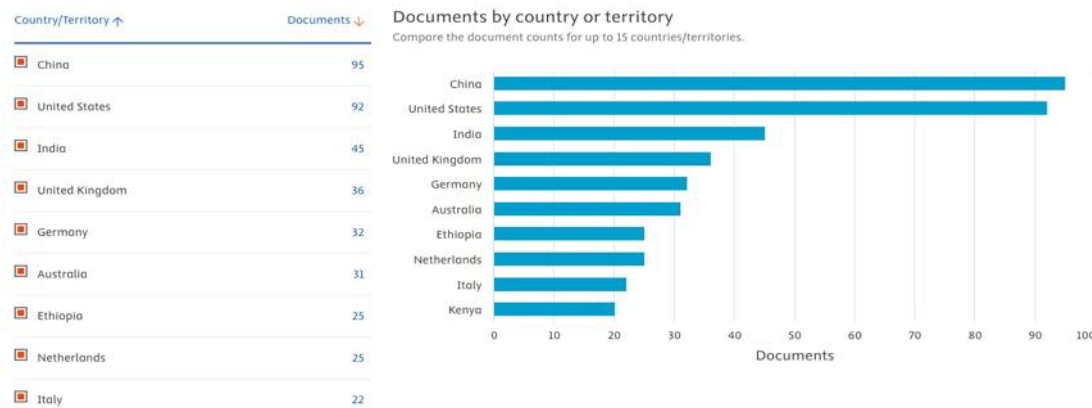


Figure 4. Top Contributing Countries in Socio-Technical Transition Research

3.4 Social Structure of Scientific Collaboration

The social structure of the research field was examined through author productivity and collaboration indicators. Table 2 presents the most productive authors, their citation counts, and total link strength values.

Table 2. Most Productive Authors and Collaboration Strength

No.	Author	Documents	Quotes	Total link strength
1	Strong, Robert	5	83	11
2	Klerkx,laurent	5	186	1
3	Lee,chin-ling	4	74	11
4	Abdoulaye, tahirou	4	189	4
5	Brown, Brendan	3	34	10
6	Ma,Wanglin	3	38	6
7	Chi, Liang, Liang.	3	51	4
8	Li,yajuan	3	52	4
9	Thierfelder, Christian	3	57	4
10	Vecchio, yari	3	168	4

Among the leading contributors, Strong recorded the highest number of publications (five documents), followed by Klerkx, who also published five documents. However, Klerkx accumulated substantially higher citation counts (186 citations), indicating a stronger intellectual influence on the field. Abdoulaye also demonstrated significant scholarly impact with 189 citations despite publishing only four documents.

The total link strength values reveal active collaboration networks among researchers working on agricultural innovation, digital transformation, and sustainability transitions. Strong and Lee exhibited the highest collaboration intensity, suggesting their central role in connecting different research groups. These findings indicate that socio-technical transition research has evolved through interdisciplinary and international collaboration involving scholars from agricultural sciences, innovation studies, sustainability research, and rural development.

Despite increasing collaboration, the network remains concentrated among institutions located in Europe, North America, and East Asia. Researchers from developing countries continue to face challenges related to research capacity, funding availability, and access to scientific networks, highlighting persistent inequalities in global knowledge production.

3.5 Conceptual Structure of the Research Field

The conceptual structure of the literature was analyzed using keyword co-occurrence analysis in VOSviewer. The resulting network visualization (Figure 5) reveals several interconnected thematic clusters that collectively define the intellectual landscape of socio-technical transition research in agriculture.

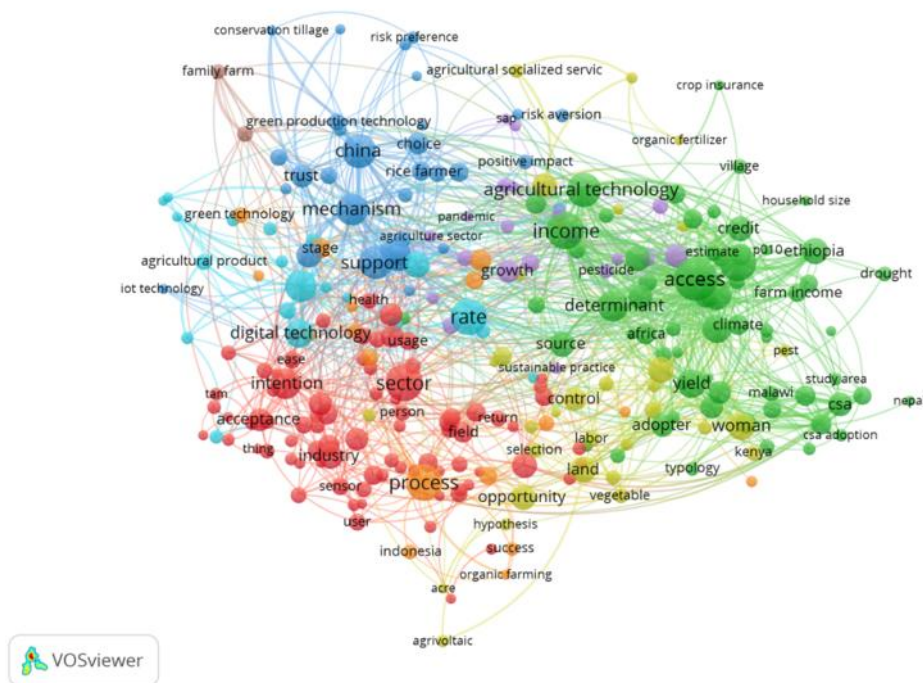


Figure 5. Keyword Co-occurrence Network of Socio-Technical Transition Research

Keywords such as “agricultural technology,” “access,” “income,” “digital technology,” “support,” and “adopter” occupy central positions within the network, indicating their importance in shaping contemporary research discussions.

The green cluster primarily focuses on technology adoption, agricultural productivity, climate adaptation, and rural livelihoods. Keywords such as “access,” “yield,” “farm income,” “climate,” and “woman” suggest growing attention to the social and economic impacts of technological innovation, particularly in developing-country contexts.

The blue cluster emphasizes institutional support mechanisms, trust, agricultural services, and policy interventions. The prominence of keywords such as “support,” “trust,” and “agricultural technology” indicates that successful technological transitions depend not only on technological availability but also on enabling institutional environments.

The red cluster is associated with behavioral dimensions of technology adoption, including “intention,” “acceptance,” “digital technology,” and “user.” This cluster reflects the continued influence of technology adoption theories such as the Diffusion of Innovation (DOI) theory,

Technology Acceptance Model (TAM), and Unified Theory of Acceptance and Use of Technology (UTAUT).

The yellow cluster highlights sustainability-oriented innovations, including “organic farming,” “sustainable practice,” and “agrivoltaic.” The emergence of these topics indicates a growing shift from productivity-oriented innovation toward sustainability-centered agricultural transformation. The conceptual structure demonstrates that socio-technical transitions in agriculture involve complex interactions among technological innovation, institutional support, behavioral change, social inclusion, and sustainability objectives.

3.6 Intellectual Structure and Knowledge Foundations

The intellectual structure of the field was examined through co-citation analysis. Figure 6 reveals several interconnected clusters representing influential streams of research that have shaped the development of socio-technical transition studies in agriculture.

One prominent cluster is centered on Groher et al. (2020), whose work focuses on precision agriculture, digital farming systems, and technological innovation in agricultural production. This cluster represents the technological dimension of agricultural transformation and emphasizes the role of digital technologies in improving farm management and productivity.

A second influential cluster is associated with Gabriel and Gandorfer (2023), whose work addresses sustainability transitions, governance arrangements, and institutional dimensions of agricultural innovation. This stream highlights the importance of social and institutional contexts in shaping technological change.

Additional clusters connected through Ammann and related authors demonstrate the integration of technology adoption research with broader sustainability and innovation frameworks. The links among these clusters indicate increasing convergence between agricultural technology studies, innovation systems research, and sustainability transition scholarship.

The co-citation network therefore illustrates the evolution of the field from isolated studies of technology adoption toward a more integrated understanding of socio-technical transitions that incorporates technological, social, institutional, and environmental dimensions.

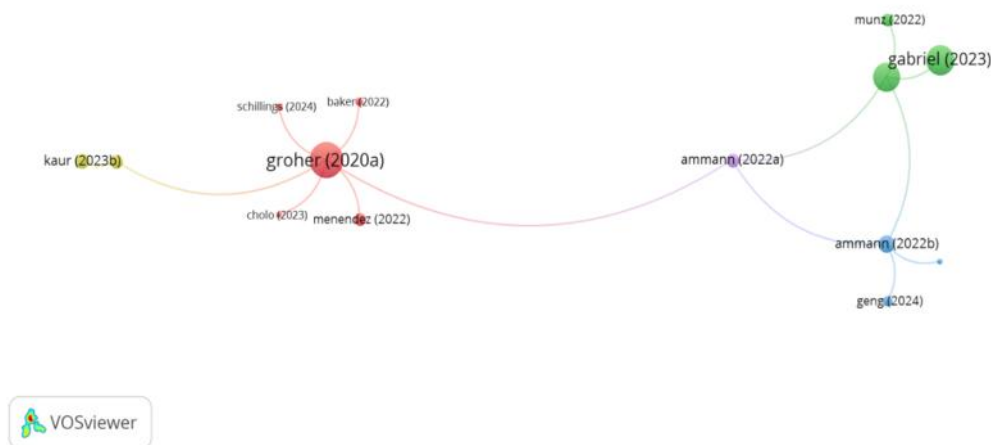


Figure 6. Co-citation Network of Influential Publications

3.7 Future Research Directions

The bibliometric findings suggest that future research should move beyond examining technology adoption as an isolated phenomenon and instead focus on understanding broader socio-technical transition processes. Several emerging themes warrant further investigation.

First, the increasing prominence of artificial intelligence, big data analytics, and digital platforms suggests growing opportunities to explore AI-enabled agricultural transitions. Second, climate-smart agriculture and resilience-oriented innovation systems are likely to become major research priorities as agricultural systems face increasing environmental uncertainty.

Third, issues of digital inclusion, gender equity, and technological accessibility require greater attention, particularly in developing countries where technological benefits are often unevenly distributed. Fourth, future studies should investigate how governance arrangements, institutional support systems, and policy frameworks influence the success of agricultural transitions. Finally, comparative studies between Global North and Global South contexts would provide valuable insights into how socio-technical transitions can support sustainable and inclusive agricultural development under diverse socio-economic conditions.

The evolution of the field indicates a gradual shift from technology-centered approaches toward more holistic perspectives that recognize the interconnected roles of technology, society, institutions, and sustainability in shaping the future of agriculture.

3.8 Discussion

The findings of this study demonstrate that research on socio-technical transitions in agriculture has expanded rapidly over the last five years, reflecting growing scholarly interest in understanding how technological innovation interacts with social, institutional, and environmental dimensions of agricultural transformation. The increasing publication trend observed between 2020 and 2024 suggests that agricultural transitions are increasingly viewed as complex systemic processes rather than merely technological modernization efforts. This shift is consistent with broader developments in sustainability transition research, which emphasize the co-evolution of technology, institutions, governance systems, and social practices.

The conceptual structure analysis revealed that keywords such as agricultural technology, access, income, digital technology, and adopter occupy central positions within the knowledge network. This finding suggests that contemporary research increasingly focuses on the relationship between technological innovation and socio-economic outcomes. The prominence of keywords associated with access, income, and adoption indicates that the success of agricultural technologies is strongly influenced by farmers' ability to access resources, knowledge, infrastructure, and institutional support. Therefore, socio-technical transitions in agriculture cannot be understood solely through technological performance indicators but must also consider issues of inclusion, equity, and social empowerment.

The identified thematic clusters further highlight the multidimensional nature of agricultural transformation. This finding is consistent with recent empirical evidence showing that digital advisory services contribute not only to technology adoption but also to the development of farmers' capacity, which subsequently enhances agricultural resilience and adaptive capability (Mursalat et al., 2026). Such evidence supports the view that socio-technical transitions are fundamentally shaped by learning processes and human capacity development rather than technological innovation alone. The adoption-oriented cluster reflects the continued influence of technology adoption theories, particularly the Diffusion of Innovation (DOI) framework and the Technology Acceptance Model (TAM), which remain dominant in explaining farmers' behavioral responses to technological change. However, the emergence of clusters related to climate adaptation, sustainability, gender, and institutional support indicates that the field is gradually moving beyond individual adoption decisions toward broader systemic perspectives. This evolution suggests increasing recognition that technological innovations generate social consequences that extend beyond farm-level productivity and encompass livelihood resilience, environmental sustainability, and community development.

The intellectual structure analysis reinforces this transition toward systemic thinking. The co-citation network revealed strong connections between studies focusing on digital agriculture, precision farming, sustainability transitions, and agricultural innovation systems. Influential works associated with Groher and Gabriel demonstrate how the field has evolved from examining technological tools and farm management practices to addressing governance mechanisms, institutional arrangements, and sustainability outcomes. This intellectual convergence reflects the growing integration of agricultural sciences, innovation studies, sustainability research, and rural development scholarship.

These findings can be interpreted through the lens of the Multi-Level Perspective (MLP), which conceptualizes socio-technical transitions as interactions among niche innovations, dominant socio-technical regimes, and broader landscape pressures. In the agricultural context, digital technologies such as artificial intelligence, precision agriculture, IoT systems, and digital advisory services represent niche innovations that challenge conventional agricultural practices. Their diffusion is shaped by

existing agricultural regimes, including extension systems, market structures, policy frameworks, and institutional arrangements. Simultaneously, external pressures such as climate change, food insecurity, environmental degradation, and global market uncertainty create landscape conditions that accelerate the demand for agricultural transformation. The increasing research attention observed in this study suggests that these three levels are becoming increasingly interconnected within contemporary agricultural systems.

The social structure analysis provides additional insights into global knowledge production patterns. The dominance of China and the United States reflects their substantial investments in agricultural innovation, digital infrastructure, and research and development. However, the growing contributions from countries such as India, Ethiopia, and Kenya indicate that socio-technical transitions are increasingly relevant in developing-country contexts. These countries often face significant challenges related to food security, climate vulnerability, and limited agricultural resources, making technological innovation a strategic pathway for sustainable development. Nevertheless, disparities in research capacity and technological access remain evident, highlighting the persistence of a global digital divide within agricultural transformation processes.

An important finding emerging from the conceptual network is the increasing visibility of themes related to gender, access, and social inclusion. Although technological innovation is frequently promoted as a universal solution for agricultural development, the literature suggests that its benefits are often unevenly distributed. Differences in education, digital literacy, gender, economic resources, and institutional support can create unequal opportunities for technology adoption. Consequently, socio-technical transitions may unintentionally reproduce or even intensify existing social inequalities if inclusiveness is not explicitly incorporated into innovation policies and implementation strategies. From this perspective, approaches emphasizing participatory innovation, farmer-centered technology design, and inclusive governance become increasingly important.

Overall, the findings suggest that future agricultural transformation should be understood as a socio-technical process rather than a purely technological one. Sustainable agricultural transitions require not only technological innovation but also supportive institutions, effective governance mechanisms, social learning processes, and equitable access to resources. The convergence of technological, social, and environmental concerns identified in this study indicates that future research should increasingly adopt interdisciplinary approaches capable of capturing the complexity of agricultural transition processes across different socio-economic and geographical contexts.

4. Conclusion

This study provides a comprehensive overview of the development of research on socio-technical transitions in agriculture through the integration of bibliometric analysis and systematic literature review approaches. By analyzing 777 publications indexed in the Scopus database between 2020 and 2024, the study mapped publication trends, geographical distribution, scientific collaboration patterns, conceptual structures, and intellectual foundations that shape this rapidly evolving field.

The findings reveal a substantial increase in scholarly interest in socio-technical transitions in agriculture over the past five years, indicating the growing importance of understanding agricultural transformation as a multidimensional process involving technological innovation, social change, institutional adaptation, and sustainability objectives. China and the United States emerged as the leading contributors to scientific production, while the increasing participation of countries such as India, Ethiopia, and Kenya highlights the global relevance of agricultural technological transitions, particularly in addressing food security, climate resilience, and rural development challenges.

The conceptual structure analysis identified several dominant themes, including agricultural technology, digital transformation, technology adoption, access to resources, income generation, sustainability, and climate adaptation. These themes demonstrate that contemporary research increasingly recognizes that technological innovation cannot be separated from social, economic, and institutional contexts. The intellectual structure analysis further revealed the convergence of multiple research traditions, including digital agriculture, innovation systems, sustainability transitions, and technology adoption studies, indicating the emergence of a more integrated understanding of agricultural transformation.

The study also confirms that socio-technical transitions in agriculture extend beyond productivity enhancement and technological efficiency. The literature increasingly emphasizes issues related to social inclusion, gender equity, institutional support, governance arrangements, and equitable access to innovation. Consequently, successful agricultural transitions depend not only on technological advancements but also on the capacity of institutions, communities, and policy systems to support inclusive and sustainable change.

From a theoretical perspective, the findings support the relevance of socio-technical transition frameworks, particularly the Multi-Level Perspective (MLP), in explaining how technological innovations interact with existing agricultural regimes and broader landscape pressures such as climate change, market uncertainty, and sustainability challenges. The results further demonstrate the value of interdisciplinary approaches that integrate agricultural sciences, innovation studies, rural sociology, sustainability research, and development studies in understanding complex agricultural transformation processes.

This study contributes to the literature by providing a systematic mapping of the global knowledge landscape on socio-technical transitions in agriculture and identifying key research gaps and emerging themes. Future research should focus on artificial intelligence-enabled agriculture, climate-smart innovation systems, digital inclusion, gender-sensitive technological transitions, and governance mechanisms that support equitable agricultural transformation. Greater attention should also be given to comparative studies between Global North and Global South contexts, as well as mixed-method approaches that combine large-scale data analytics with in-depth community-based investigations. The findings suggest that the future of agriculture will be shaped not only by technological innovation but also by the ability of societies and institutions to ensure that technological transitions are inclusive, sustainable, and responsive to the diverse needs of farming communities.

References

- Admiraal, M., Lucquin, A., von Tersch, M., Craig, O. E., & Jordan, P. D. (2020). The adoption of pottery on Kodiak Island: Insights from organic residue analysis. *Quaternary International*, 554, 128–142. <https://doi.org/10.1016/j.quaint.2020.06.024>
- Annosi, M. C., Ráez, R. M. O., Appio, F. P., & Del Giudice, T. (2022). An integrative review of innovations in the agricultural sector: The roles of agency, structure, and their dynamic interplay. *Technological Forecasting and Social Change*, 185. <https://doi.org/10.1016/j.techfore.2022.122035>
- Ciruela-Lorenzo, A. M., Del-Aguila-Obra, A. R., Padilla-Meléndez, A., & Plaza-Angulo, J. J. (2020). Digitalization of agri-cooperatives in the smart agriculture context. Proposal of a digital diagnosis tool. *Sustainability (Switzerland)*, 12(4). <https://doi.org/10.3390/su12041325>
- Dadzie, S. K. N., Ndebugri, J., Inkoom, E. W., & Akuamoah-Boateng, S. (2022). Social networking and risk attitudes nexus: implication for technology adoption among smallholder cassava farmers in Ghana. *Agriculture and Food Security*, 11(1). <https://doi.org/10.1186/s40066-022-00376-3>
- Darmawan, D. P., Arisena, G. M. K., Djelantik, A. A. W. S., Krisnandika, A. A. K., Utari, N. K. S., & Korri, N. T. L. (2023). Farmers' Independence Level in the Urban Area of Subak Sembung Denpasar City, Bali Province, Indonesia. *Journal of Agricultural Sciences - Sri Lanka*, 18(1), 40–54. <https://doi.org/10.4038/jas.v18i1.10097>
- De Oliveira, F. B. J., Fernandez, A., Hernández, J. E., & del Pino, M. (2022). Design Thinking and Compliance as Drivers for Decision Support System Adoption in Agriculture. *International Journal of Decision Support System Technology*, 15(2). <https://doi.org/10.4018/IJDSST.315643>
- Dutta, P., Choi, T.-M., Somani, S., & Butala, R. (2020). Blockchain technology in supply chain operations: Applications, challenges and research opportunities. *Transportation Research Part E: Logistics and Transportation Review*, 142. <https://doi.org/10.1016/j.tre.2020.102067>
- El Fartassi, I., Milne, A. E., El Alami, R., Rafiqi, M., Hassall, K. L., Waine, T. W., ... Corstanje, R. (2023). Evidence of collaborative opportunities to ensure long-term sustainability in African farming. *Journal of Cleaner Production*, 392. <https://doi.org/10.1016/j.jclepro.2023.136170>
- Gabriel, A., & Gandorfer, M. (2023). Adoption of digital technologies in agriculture—an inventory in a european small-scale farming region. *Precision Agriculture*, 24(1), 68–91. <https://doi.org/10.1007/s11119-022-09931-1>

- Giua, C., Materia, V. C., & Camanzi, L. (2022). Smart farming technologies adoption: Which factors play a role in the digital transition? *Technology in Society*, 68. <https://doi.org/10.1016/j.techsoc.2022.101869>
- Groher, T., Heitkämper, K., & Umstätter, C. (2020). Digital technology adoption in livestock production with a special focus on ruminant farming. *Animal*, 14(11), 2404–2413. <https://doi.org/10.1017/S1751731120001391>
- Groher, T., Heitkämper, K., Walter, A., Liebisch, F., & Umstätter, C. (2020). Status quo of adoption of precision agriculture enabling technologies in Swiss plant production. *Precision Agriculture*, 21(6), 1327–1350. <https://doi.org/10.1007/s11119-020-09723-5>
- Gyawali, B. R., Paudel, K. P., Jean, R., & Banerjee, S. “. (2023). Adoption of computer-based technology (CBT) in agriculture in Kentucky, USA: Opportunities and barriers. *Technology in Society*, 72. <https://doi.org/10.1016/j.techsoc.2023.102202>
- Hidayati, B., Qurrata, V. A., & Huang, W. (2023). The Digital Agriculture Model For Sustainable Food System: An Analysis Of Agricultural Technology Adoption In East Java, Indonesia. *Journal of Sustainability Science and Management*, 18(4), 173–191. <https://doi.org/10.46754/jssm.2023.04.013>
- Jain, M., Soni, G., Verma, D., Baraiya, R., & Ramtiyal, B. (2023). Selection of Technology Acceptance Model for Adoption of Industry 4.0 Technologies in Agri-Fresh Supply Chain. *Sustainability (Switzerland)*, 15(6). <https://doi.org/10.3390/su15064821>
- Jara-Rojas, R., Canales, R., Gil, J. M., Engler, A., Bravo-Ureta, B., & Bopp, C. (2020). Technology adoption and extension strategies in mediterranean agriculture: The case of family farms in Chile. *Agronomy*, 10(5). <https://doi.org/10.3390/agronomy10050692>
- Johnson, D., Almaraz, M., Rudnick, J., Parker, L. E., Ostoja, S. M., & Khalsa, S. D. S. (2023). Farmer Adoption of Climate-Smart Practices Is Driven by Farm Characteristics, Information Sources, and Practice Benefits and Challenges. *Sustainability (Switzerland)*, 15(10). <https://doi.org/10.3390/su15108083>
- Li, B., Guo, B., Zhu, Q., & Zhuo, N. (2023). Impact of Technical Training and Personalized Information Support on Farmers’ Fertilization Behavior: Evidence from China. *Sustainability (Switzerland)*, 15(11). <https://doi.org/10.3390/su15118925>
- Liu, D., Huang, Y., & Luo, X. (2023). Farmers’ technology preference and influencing factors for pesticide reduction: evidence from Hubei Province, China. *Environmental Science and Pollution Research*, 30(3), 6424–6434. <https://doi.org/10.1007/s11356-022-22654-0>
- Man, N., Abdulmumini, U., & Siaw, S. Y. (2024). Factors Influencing Participation of Rural Women Farmers in Agricultural Activities in Ranau, Sabah, Malaysia: An Exploratory Factor Analysis. *Caraka Tani: Journal of Sustainable Agriculture*, 39(2), 255–268. <https://doi.org/10.20961/carakatani.v39i2.79372>
- Nadeeshani Silva, K. N. (2023). Social Network to Accelerate Agricultural Technology Adoption: Evidence from Hambanthota District, Sri Lanka. *Indian Journal of Extension Education*, 59(1), 1–6. <https://doi.org/10.48165/IJEE.2023.59101>
- Nagariya, R., Mukherjee, S., Baral, M. M., Patel, B. S., & Venkataiah, C. (2022). The Challenges of Blockchain Technology Adoption in the Agro-based Industries. *International Journal of Mathematical, Engineering and Management Sciences*, 7(6), 949–963. <https://doi.org/10.33889/IJMEMS.2022.7.6.059>
- Mursalat, A., Jamil, M. H., Salam, M., Sulaiman, A. A., Hastang, & Bahrin, A. H. (2026). Building farmers capacity for sustainable agricultural resilience through the diffusion of innovations in ICT advisory using partial least squares structural equation modeling. *Discover Sustainability*. <https://doi.org/10.1007/s43621-026-03441-0>
- Perelli, C., Cacchiarelli, L., Peveri, V., & Branca, G. (2024). Gender equality and sustainable development: A cross-country study on women’s contribution to the adoption of the climate-smart agriculture in Sub-Saharan Africa. *Ecological Economics*, 219. <https://doi.org/10.1016/j.ecolecon.2024.108145>
- Phiri, A. T., Charimbu, M., Edewor, S. E., & Gaveta, E. (2022). Sustainable Scaling of Climate-Smart Agricultural Technologies and Practices in Sub-Saharan Africa: The Case of Kenya, Malawi, and Nigeria. *Sustainability (Switzerland)*, 14(22). <https://doi.org/10.3390/su142214709>

- Phuong, L. T. H., Khanh, H. L. P., Beckman, M., Hoan, D. T., Phung, L. D., & Sen, L. T. H. (2024). From Perception to Practices: Adoption of Ecosystem-Based Adaptation in Vietnam Upland Areas—A Case Study in Thua Thien Hue Province. *Sustainability (Switzerland)*, 16(22). <https://doi.org/10.3390/su162210094>
- Teklu, A., Simane, B., & Bezabih, M. (2023). Multiple adoption of climate-smart agriculture innovation for agricultural sustainability: Empirical evidence from the Upper Blue Nile Highlands of Ethiopia. *Climate Risk Management*, 39. <https://doi.org/10.1016/j.crm.2023.100477>
- Thangjam, B., Jha, K. K., Sharma, S., & Singh, H. (2024). Factors Affecting on Adoption of Sustainable Agricultural Practices in Manipur. *Indian Journal of Extension Education*, 60(2), 66–70. <https://doi.org/10.48165/IJEE.2024.60213>
- Vallury, S., Cook, N. J., & Nelson, D. R. (2024). Social inequalities shape climate change adaptation among Indian farmers. *Environmental Research Letters*, 19(11). <https://doi.org/10.1088/1748-9326/ad7d1d>
- Vecchio, Y., Agnusdei, G. P., Miglietta, P. P., & Capitanio, F. (2020). Adoption of precision farming tools: The case of Italian farmers. *International Journal of Environmental Research and Public Health*, 17(3). <https://doi.org/10.3390/ijerph17030869>
- Wang, G., Lu, Q., & Capared, S. C. (2020). Social network and extension service in farmers' agricultural technology adoption efficiency. *PLoS ONE*, 15(7 July). <https://doi.org/10.1371/journal.pone.0235927>
- Yatribi, T. (2020). Factors Affecting Precision Agriculture Adoption: A Systematic Literature Review. *ECONOMICS - Innovative and Economics Research Journal*, 8(2), 103–121. <https://doi.org/10.2478/eoik-2020-0013>