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Mapping the research of digital transformation in agriculture

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Abstract: This study aims to systematically map the rapidly growing research landscape on Digital Transformation in Agriculture (DTA). A bibliometric analysis was conducted on 96 documents related to DTA, sourced from the Scopus database. The research methodology encompasses co-occurrence keyword and co-citation analyses, focusing on 2019 to 2023. The study reveals a significant annual increase in the volume of publications, with Russia emerging as the leading contributor. The co-word analysis identifies three dominant research themes, characterized by 17 keywords with a minimum occurrence of five times. The clusters are innovation and agrifood-tech, sustainable agricultural development and digital economy, digitalization of agriculture, and Russia. The co-citation analysis for cited authors created a network of four clusters of innovation efforts in agriculture, information systems on farms, the role of business models and dynamic capabilities in sustainable intensification, and the challenges, opportunities, and sustainability of DTA. The findings indicate that research on DTA is still developing, with significant research gaps remaining. This study aims to contribute to the field's academic literature and practical applications.

Keywords: Digital transformation, agriculture, bibliometric.

1. Introduction

Digital transformation (DT) has recently garnered significant attention from scholars and experts as a pivotal force driving economic advancement in the digital era. The body of research on DT is expanding across various fields. Digitalization is anticipated to fundamentally reshape daily life and production processes in agriculture, as well as food supply chains and systems (Poppe et al., 2013). Several digitalization concepts have emerged in agriculture, including smart farming, agriculture 4.0, and digital agriculture (Blok & Gremmen, 2018). Irrespective of the specific terminology used, digitalization in agriculture involves various types of data, such as location, weather, behavior, and consumption, alongside the use of sensors, machinery, drones, and satellites to monitor soil, water, plants, and human activities both on-farm and along the value chains (Eastwood et al., 2019). The potential impact of this digitalization on agriculture is significant, as it is expected to enhance knowledge exchange, promote widespread data utilization, and improve crisis monitoring within the agricultural sector (Baumüller, 2016). The application of technology aims to boost productivity, monitor

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post-harvest quality, and enable real-time traceability (Wolfert et al., 2017). This potential impact underscores the importance of understanding and researching DTA. Additionally, in recent years, numerous documents have been developed addressing digital agriculture's management and institutional aspects.

Although there is increasing interest in digital agriculture across various disciplines, the scientific literature remains fragmented. This research aims to reflect, describe, and visualize the interconnections of research articles on DTA by creating a comprehensive research map. The theoretical foundation for DTA is outlined in Section 2. In Section 3, the research process and methods are introduced. Section 4 provides an in-depth evaluation of research topics through the research map. Section 5 discusses the findings, acknowledges the limitations of the research, and offers conclusions.

The article seeks to address the following research questions:

RQ1: What is the annual growth rate of publications, and how does the country distribute them?

RQ2: How do the insights from the articles relate to topic clusters, and what new research directions emerge from co-citation analysis?

RQ3: What are the main research topics in DTA based on co-occurrence keyword analysis?

To answer these questions, the article presents an interdisciplinary perspective. First, it integrates insights from social sciences, science and technology, and policy research to demonstrate diverse and complementary perspectives on digital agriculture. These perspectives highlight digitalization's positive and negative impacts on the sustainable development of agriculture, food systems, and rural areas, emphasizing the need to support stakeholders such as farmers, advisors, policymakers, and researchers. Second, it adopts an interdisciplinary approach by bridging the social sciences with the natural, engineering, and life sciences. This approach outlines future research directions and new questions for the social sciences of digitalization, helping researchers from other disciplines to clarify the conditions for developing, testing, deploying, and scaling new digital technologies.

2. Literature review

2.1. Digital transformation

At the industry level, DT encompasses substantial changes occurring within society and industries through digital technologies (Agarwal et al., 2010). At the organizational level, DT is how businesses integrate technology with strategy, processes, and culture to enhance business performance (Bharadwaj et al., 2013). Consequently, DT is a multifaceted process that alters organizational attributes by amalgamating information technology, computing, communications, and connectivity. The dimensions of DT include (1) Smart products and smart services, which involve integrating digital technology into products to collect user data for a deeper understanding of customer behavior; (2) Smart manufacturing, which requires high levels of automation and connectivity in machines, technological equipment, and production lines; (3) Smart management, where businesses invest in advanced management systems that leverage technology to operate intelligent production lines and create innovative products (Vial, 2019).

2.2. Digital transformation in agriculture

In 2007, the concept of Climate-Smart Agriculture (CSA) emerged in various forms. With the advent of digital technology in agriculture, CSA has evolved to include terms such as Smart Agriculture, Digital Agriculture, and Agriculture 4.0. CSA aims to address climate change and food security challenges by sustainably increasing productivity, enhancing resilience, and reducing greenhouse gas emissions to achieve national security and development goals (Okolie et al., 2022).

3. Methodology

The authors employed a bibliometric method focusing on documents with DTA keywords to address the research questions. Bibliometrics involves the application of statistical methods to bibliographic data, particularly within the realms of science, library, and information science (Pritchard, 1969).

In this study, the authors used documents indexed in the Scopus database. Scopus has a broader scope in the social sciences and humanities than WoS (Guz & Rushchitsky, 2009; Tabacaru, 2019). Furthermore, Scopus provides a range of advanced search functions that address various research needs, including document retrieval, citation analysis, and scientific impact assessment (Falagas et al., 2008). This database is often recommended for bibliographic reviews (Donthu et al, 2021) because it provides comprehensive and high-quality data for evaluation. The authors applied a three-phase approach guided by the Preferred

Reporting Items for Systematic Review and Meta-Analysis (PRISMA) to establish the research process. The phases are Identification, Screening, and Inclusion.

3.1. Identification

The selection of research articles constitutes the initial step of this study. Each selected research paper must contain at least one of the following keywords: digital transformation, OR digital business transformation, OR digitalization, OR digital innovation, OR digitalisation AND agriculture, OR farming, OR agribusiness, OR agronomics. The initial screening process, conducted on March 16, 2024, identified 314 documents from the Scopus database. Subsequent screening was limited to documents published up to 2023, as data from 2024 was incomplete, resulting in 285 documents.

To refine the selection, Scopus filters were applied to categorize the documents broadly. The author first filtered by industry, selecting only those within Environmental Science, Agricultural and Biological Sciences, Business, Management, Accounting, Social Sciences, Economics, Econometrics, Finance, Decision Sciences, Psychology, and Multidisciplinary fields. This step reduced the dataset to 206 documents. The following filter was applied to document type, retaining only Article, Book, Book Chapter, and Conference paper. This further reduced the dataset to 187 documents. Finally, after excluding documents in languages other than English, the number of documents was reduced to 173.

3.2. Screening

In this step, the 173 documents were screened based on their titles and abstracts to determine their eligibility according to topical relevance. Many articles were excluded due to their focus on engineering, planetary, and natural sciences. Additionally, some articles were excluded for combining English and Russian, excluding 16 documents. Consequently, 157 articles remained for full-text review. Further screening excluded 61 articles that did not provide full-text access, leaving a final set of 96 open-access documents.

3.3. Inclusion

After step two, the authors compiled a database of the 96 documents, exported to CSV format, for data analysis. To improve data accuracy, the data were synchronized according to the guidelines provided by (van Eck & Waltman, 2013). The data were analyzed in three stages. The first stage involved a descriptive analysis to present basic information about the 96 documents. The second stage was co-citation analysis, a technique determining the number of citations an article receives from two different articles and the relationship between articles citing the same document (Small, 1973). The final stage was co-occurrence keyword analysis, which aggregates the number of times keywords appear together in articles. The study employed VOSviewer software to support the co-citation and occurrence keyword network analysis.

4. Results

4.1. Volume, growth pattern, and geographical distribution

The first publication in the dataset appeared in 2019, with a total of 8 documents. From 2021 to 2023, there was a sharp increase in the number of publications, rising from 20 to 76, resulting in a significant growth in the overall number of publications (n = 96, accounting for 79.2% of the total) within just three years. As of the time of searching in 2021, there were 29 publications on this topic. Among the 96 scientific documents, 51.04% (49 publications) are articles, 42.7% (41 publications) are conference papers, and the remaining 6.3% are books and book chapters (6 publications).

The number of publications based on the journals in which they were published: Statistical results indicate that the 96 documents were published across 45 academic journals, covering research topics such as Business, Agriculture, Food Studies, Social Sciences, and Computer Science. Notably, *Sustainability (Switzerland)* and *Agricultural Systems* stand out in both the number of publications and evaluation indicators, with five publications (5.21%) and four publications (4.17%), respectively. Both journals belong to the Q1 and Q2 groups and have high H-Indexes.

Regarding the distribution of publications by country, the analysis reveals that publications originate from 46 countries across various regions worldwide. Among these countries, 26 have affiliations with each other. Russia leads with the highest number of publications (42 articles), followed by the United States (7 articles), Australia, the Netherlands, and China (6 articles each), Italy (5 articles), and the United Kingdom, Northern Ireland, Belarus, and Brazil (4 articles each).

4.2. Co-citation analysis

The study encompassed 8,809 authors. Co-citation analysis lacks a universally agreed-upon

threshold; small thresholds may lack accuracy, while high thresholds may exclude emerging research topics that have not yet garnered many citations (Trujillo & Long, 2018). Therefore, the author set an optimal minimum co-citation threshold of 10 (Boyack & Klavans, 2010) in VOSviewer to visualize relationships among frequently co-cited authors. This threshold was chosen because meaningful clusters are best depicted at this level. The resulting map identified 32 authors organized into 4 clusters, as shown in Figure 1.

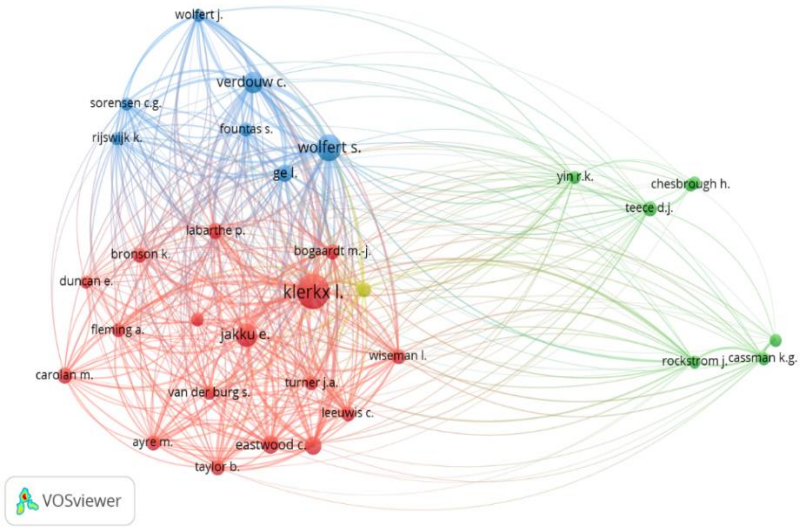

Figure 1: The co-citation of DTA research
Source: Scopus data analysis results, June 2024.

Cluster 1 (red) depicts innovation endeavors in agriculture, led by 17 authors, including Klerkx Laurens, Jakku Emma, Turner James A, Nettle Ruth, Callum R Eastwood, and others. The theoretical foundation of this cluster is "the principle theoretical." It revolves around "organizational identity," addressing digital agriculture's changing nature, pace, and landscape, and "digi-grasp," focusing on this domain's ability, practices, services, customers, partners, purpose, and values. Findings reveal that digital agriculture often revolves around farm-centric approaches, tailoring organizational capabilities, practices, and services to meet the needs of customers and partners rather than pursuing a strategic and transformative business model (Rijswijk et al., 2019). Several studies highlight potential transformations in farm business models, decision-making processes, and the equity implications of new technologies across various value chain stages (Fleming et al., 2021). Research in this cluster also examines how co-design processes support farm consultants in adapting their traditional consulting practices by engaging with the social, material, and symbolic aspects of digital software (digiware) in smart farming, thereby enhancing decision-making capabilities at farm management levels (Ayre et al., 2019).

Cluster 2 (blue) explores the connections among researchers dedicated to elucidating information systems on farms. This cluster comprises seven authors, with Wolfert Sjaak and Verdouw Cor as its leading figures. Wolfert Sjaak is a prominent contributor, emphasizing the significant role of digital technology in agricultural innovation. Central to this cluster's framework is a multi-agent approach that involves testing and uses case development, engaging a range of multidisciplinary activities (Wolfert et al., 2023). The foundational theories in this cluster include the theory of multiple rationalities (Ge & Bogaardt, 2015) and farm management information systems (FMIS) (Fountas et al., 2015). Additionally, user-centered studies focusing on modeling information flows are critical (Sorensen et al., 2010).

Cluster 3 (green) elucidates the connections among researchers examining the role of business models and dynamic capabilities in sustainable intensification. This cluster includes the seven most cited authors: Teece David J., Robert K. Yin, and Kenneth G. Cassman. These authors emphasize a roadmap toward sustainable intensification through business model innovation, relationships with technology partners, and the power of dynamic capabilities (Cassman & Grassini, 2020; Teece, 2018). The studies within this cluster enhance the understanding of innovation, implementation, and business model transformation necessary to achieve sustainable intensification.

Cluster 4 (yellow) features a single-cited author, Simon Fielke. The connections among researchers cited by Simon Fielke center on the challenges, opportunities, and sustainability of digitally transforming agriculture. Addressing these challenges necessitates building institutional, organizational, and professional capacity to anticipate and reflect on changes. The theoretical foundation of this cluster is grounded in the theory of agricultural innovation systems (AIS) (Fielke et al., 2019).

4.3. Co-occurrence keyword analysis

The co-occurrence keyword analysis included 96 documents and 512 keywords. By setting a minimum occurrence threshold of five for each keyword (van Eck & Waltman, 2017), 17 keywords met the criteria. The resulting co-word network is relatively sparse, indicating that this research topic has not yet garnered significant attention from the academic community. The analysis identified three themes.

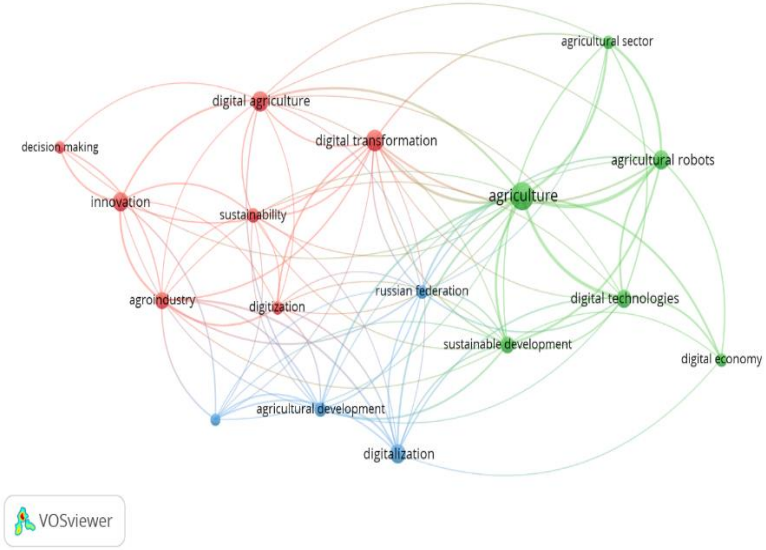

Figure 2: The co-occurrence network of DTA research
Source: Scopus data analysis results, June 2024.

Cluster 1 (red) focuses on the main keywords: DT, digitalization, agricultural DT, innovation, decision-making, agricultural industry, and sustainability. Smart agriculture is revolutionizing the agricultural sector regarding economic, social, and environmental sustainability. This cluster highlights the food industry as a critical feature of Agriculture 4.0 and can thus be named "Innovation and AgriFood-Tech." The agri-food business sector demonstrates growth potential by fostering innovation, accelerating institutional and structural changes, enhancing productivity, and introducing new products and services. Six primary concepts are identified: innovation strategy, innovation organization, innovation network, innovation process, innovation object, and innovation infrastructure (Wolfert et al., 2023).

Cluster 2 (green) concerns critical terms such as sustainable development, digital technology, agricultural robots, and the digital economy. Digital technology impacts all stages of agricultural production, transforming and improving business processes, models, and structures. From a macroeconomic perspective, the digital economy is a crucial driver of sustainable agricultural development, enhancing labor efficiency and product quality, reducing inflation and unemployment, and fostering steady economic growth. Hence, this cluster can be named "Sustainable Agricultural Development and Digital Economy." Key models and theories discussed in this cluster include ITIL-based modeling and ITSM-based management methods, Digital Twins technology (Eremina et al., 2022), blockchain technology, theory of innovation, and theory of value (Sgroi, 2022).

Cluster 3 (blue) focuses on the keywords agricultural development, digitalization, and Russia. The primary trend in agricultural development within this cluster is digitalization. Most studies in this cluster evaluate agricultural technology and emphasize the economic aspects of the technology's productivity, profitability, technical efficiency, and impact on users' livelihoods. Thus, this cluster can be named "Digitalization of Agriculture in Russia." This research topic has emerged as a significant trend in the field since 2021. Adopting digital

agriculture is crucial for the development of agriculture.

Research on DTA is mainly concentrated in developed countries, where there is better technological and financial infrastructure, facilitating the application of advanced technologies in agriculture. In contrast, in developing and underdeveloped countries, the number of studies is limited due to barriers in infrastructure, finance, and access to technology. Research on DTA in developed countries, including Russia, is essential for countries worldwide, including developing countries. Firstly, this activity helps provide solutions suitable for local conditions. Research can help identify DT solutions suitable for the specific conditions of each country, thereby helping to optimize costs and resources while increasing production efficiency. Second, this promotes supportive policies, providing a scientific basis for policymakers to develop appropriate strategies and support to encourage businesses to invest in digital technology while creating a favourable environment for sustainable agricultural development in other countries. Third, these studies help other countries analyze the impact of DT on economic, social and environmental factors, thereby making recommendations for sustainable development. Studying the solutions of a few countries helps other countries, especially developing or underdeveloped countries, learn, adapt, and assess the impact of DTA in the context of limited resources.

5. Discussion and conclusion

5.1. Discussion

The discovery of 96 documents related to DTA reveals that this is a relatively recent research topic. The Scopus database recorded the first studies on this topic in 2019, with most documents published in prestigious journals with high citation indexes. Notably, the journals "Sustainability (Switzerland)" and "Agricultural Systems" have the most significant number of publications related to DTA.

Table 1: Main theories in DTA topic research

Author	Title	Journal name	Main theories
Fielke et al. (2019)	Conceptualising the DAIS: implications of the "digitalisation of agricultural innovation systems" on technology and policy at multiple levels	NJAS: Wageningen Journal of Life Sciences	Agricultural Innovation Systems (AIS) theorisation
Eastwood et al. (2017)	Dynamics and distribution of public and private research and extension roles for technological innovation and diffusion: Case studies of the implementation and adaptation of precision farming technologies	Journal of Rural Studies	The principle theoretical
Eremina et al. (2022)	The use of digital technologies to improve the information support of agricultural enterprises	International Journal of Technology	ITIL-based modeling
Wolfert et al. (2023)	Digital innovation ecosystems in agri-food: Design principles and organizational framework	Agricultural Systems	The lean multi-actor approach
Vlachopoulou et al. (2021)	Analyzing agrifood tech and e-business models	Sustainability (Switzerland)	"AgriFoodTech" business models
Zhu et al. (2023)	Comprehensive evaluation and promotion strategy of agricultural digitalization level	Sustainability (Switzerland)	The ESDA method
Sgroi (2022)	The role of blockchain for food safety and market efficiency	Journal of Agriculture and Food Research	The economic theory of innovation and the theory of value examined

Source: Authors.

Co-word analysis produced keyword maps of research publications, reviews, and articles, identifying three key themes: Cluster 1 is "Innovation and AgriFood-Tech," Cluster 2 is "Sustainable Agricultural Development and Digital Economy," and Cluster 3 is "Digitalization of Agriculture and Russia." Additionally, co-citation analysis for cited authors created a network of four clusters: innovation efforts in agriculture, information systems on farms, the role of business models and dynamic capabilities in sustainable intensification, and the challenges, opportunities, and sustainability of digitally

transforming the agricultural sector. Current research has predominantly focused on conceptualizing the topic and introducing opportunities and challenges for applying information technology or digitizing agricultural activities. This focus may partly determine the theoretical foundation used for research on DTA. The theories revolve around optimizing processes and improving efficiency in agricultural systems through the support of digital technology. They emphasize innovation and multi-stakeholder interaction, focus on improving efficiency and sustainability, and apply digital technology to improve decision-making processes. Details are presented in Table 1.

Despite their similarities, these theories also have significant differences. AIS is a broad theory encompassing elements from policy to technology, while the lean multi-actor approach focuses more on the specific roles of actors in the agricultural innovation ecosystem. Blockchain focuses on transparency and traceability in the supply chain, aiming to improve food safety, while e-business models mainly revolve around developing digital business frameworks for specific agricultural models. In addition, there is a lack of research on DT's process, level, and method and a lack of exploratory studies on DTA. This gap presents an opportunity for future research to incorporate diverse theories to explain this relationship. Combining multiple theories and methods gives researchers and practitioners a more comprehensive view of the factors affecting the DT process, from information management and technological innovation to sustainability and supply chain efficiency. This promotes modern agriculture's development and supports policy strategies to optimize resources and improve efficiency in the agricultural sector.

5.2. Suggestions for future research

DTA must be evaluated through an interdisciplinary lens to provide different perspectives and clarify any assumptions made by both parties. In this study, we identified three research themes in DTA studies. Therefore, based on bibliometric and content analysis, we propose future research directions:

For theme 1 (Innovation and AgriFood-Tech), future work might focus on the e-business models and diagnostic tools to support agri-food enterprises and cooperatives in improving supply chain efficiency and competitiveness and assessing their readiness for DT. For theme 2 (Sustainable Agricultural Development and DT), the focus is expected to address the impact of digital platforms and blockchain in enhancing transparency, traceability, and efficiency of the agri-food supply chain, and to analyze the factors predicting digital readiness and strategies to promote DT in low- and middle-income countries. Theme 3 (Digitalization of Agriculture in Russia) is predicted to undergo tremendous growth in research and practitioner interest owing to the prominence of local enablers and cross-border cooperation initiatives in developing sustainable digital technologies, focusing on DT in regional and national contexts, especially in Russia and European countries.

In addition to these general suggestions, we synthesize research avenues from the investigated literature and propose research questions for three themes in Table 2.

Table 2: Possible research avenues for three DTA research themes

Theme	Possible research avenues
Theme 1 (Innovation and agrifood-tech)	- How can e-business models improve the efficiency of agri-food supply chains? - What are the design principles and challenges when building an organizational framework for a digital innovation ecosystem in the agri-food sector? - How can digital diagnostic tools help agricultural cooperatives assess their digital readiness? - What DT strategies can help agri-food businesses improve their competitiveness? How does agri-tech 4.0 affect the quality and productivity of agricultural production? - How can social media data analysis help identify DT trends in the agri-food sector? - What digital technologies can support the optimization of production and distribution in the supply chain for niche products? - How do digital initiatives attract young people to the agricultural sector?
Theme 2 (Sustainable agricultural development and digital economy)	- How do various DT impact the decision-making processes of agricultural enterprises? - In what ways can blockchain technology improve traceability and transparency across different agricultural supply chains? How does blockchain affect trust between farmers, distributors, and consumers, and how does it impact market efficiency? - How do varying levels of digitalization affect the productivity and sustainability of agricultural enterprises? What strategies most effectively promote DT in low- and middle-income countries?

	- What indicators predict an agricultural enterprise's digital and technological transformation readiness? - How can digital technologies and frugal innovation be integrated to benefit smallholder farmers in resource-constrained environments? - How does digitalization contribute to the strategic development of agro-industrial regions in Russia compared to other countries? - How can local enablers be leveraged to increase the effectiveness of digital technologies in sustainable agricultural development? - How can digital farming contribute to strategic planning and competitiveness in the global agricultural market?
Theme 3 (Digitalization of agriculture in Russia)	- How can Russia leverage Agriculture 4.0 to enhance its competitive position in global agriculture? - What policies could enhance the competitiveness and resilience of small agricultural enterprises in Russia? - What are the long-term socioeconomic impacts of digitalization on rural development in agricultural regions? - How can cross-border initiatives like SMART4ALL support technology transfer and digital capability building in agriculture? - How can Slovakia's experience with business digitization serve as a model for other European rural regions?

Source: Authors.

5.3. Limitations and conclusion of the research

Regarding research methods, the authors employed detailed information and visualization techniques for the documents. The bibliometric method is advantageous because it can visualize relationships between scientific topics. Based on the annual number of publications evaluated from 96 academic documents, including articles, conference reports, and published book chapters, the descriptive analysis results show that this research topic has increased, especially after 2020. However, the number of publications remains limited. Most authors are from developed countries, with few studies on DTA from developing or underdeveloped countries. Moreover, the authors only used documents indexed in Scopus, excluding other databases such as Web of Science (WoS) and Google Scholar, which present additional constraints, along with the choice of keywords and language limitations. Addressing these limitations could be a direction for future research. In addition, to obtain accurate and objective results, future research should try to minimize subjectivity when selecting core research topics. To achieve this, qualitative research methods that consider expert opinions are ideal. Despite significant efforts to complete this study, data collection and analysis limitations were unavoidable. Nevertheless, this study is valuable in identifying the knowledge base, research trends, gaps, and weaknesses, laying the groundwork for further research.

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