Review

THE RELATIONSHIP BETWEEN SUSTAINABLE DEVELOPMENT AND DIGITAL TRANSFORMATION: BIBLIOMETRIC ANALYSIS

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Abstract: Digital transformation is becoming an integral component of sustainable development for different scales of activity: meta-, mega-, macro, meso-, and microlevels. The aim of the article is to identify the relationship between sustainable development and digital transformation by characterising the evolution of key patterns of scientific publications on this issue. The goal is achieved by forming a relevant sample of scientific articles based on the identification of periods of publication activity, as well as by performing bibliometric analysis of keywords coincidence to identify promising areas of research in this area. On the one hand, categories such as "sustainable development" or "sustainability" and, on the other hand, categories describing digital transformation. The generated sample of publications for the study includes 9,527 articles and conference papers indexed by the scientific metrics database Scopus for the period 1990-2023. The bibliometric analysis and visualisation of its results were carried out using the VOSviewer software product. On the basis of the visualisation maps, five clusters were identified and characterised based on the meaningful coincidence of keywords in articles and five stages of evolutionary development of the issues of sustainable development and digitalisation. Based on the analysis of empirical data, exponential growth in the number of publications in the context of the relationship between digital technologies and economic, environmental and social sustainability was confirmed (the annual increase in the number of articles on this topic is 36%). The results of the analysis can be used in future research related to sustainable development and digital transformation.

Keywords*:* sustainable development, sustainability, digital economy, digital transformation, information economy, virtual economy, information and communication technologies, the Internet of Things, Industry 4.0, smart city

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1. Introduction

Sustainable development is a priority global goal formulated and endorsed by the UN General Assembly in "Transforming our world: the 2030 Agenda for Sustainable Development" [1], which provides for the implementation of measures aimed at the optimal use of limited resources and the use of resource-saving technologies, preserving the stability of social and cultural systems, and ensuring environmental protection [2-3].

In today's dynamic environment, digital transformation is becoming the basis for achieving the outlined sustainable development goals [4]. Digital technologies and innovative solutions have the potential to improve resource efficiency, optimise production processes [5], improve access to education [6-18], health and other services, and strengthen risk management and environmental monitoring [19-29]. For example, the rapid processing of large amounts of information on pollutant emissions based on modern technologies allows us to monitor the current impact and state of the environment and to promptly implement targeted sustainable development measures aimed at its protection [30-46].

However, digital transformation can also increase social inequalities [6] if appropriate measures are not taken in a timely manner to ensure access to digital resources and opportunities for all population groups. In addition, the consumption of significant amounts of energy and resources by digital technologies may also have negative consequences for the environment [10,44]. In such circumstances, the justification of the directions of increasing the sustainability and environmental responsibility of digital technologies, as well as the study of the relationship between digital transformation and sustainable development, becomes particularly relevant.

The article has the following structure: the Literature Review section describes the research on the theoretical picture of the links between digital technologies and the main directions of sustainable development, finds gaps in the research and sets the goal; Materials and Methods describes the main data and their sources, methods and tools used to achieve the goal; Results explains the results of the research on the links between digital technologies and sustainable development; Discussions and Conclusions sections summarise the research findings, compare them with previous studies, identify limitations and prospects for further research.

2. Literature Review

Research [6,7,10,30,44] show that information and computer technologies over recent decades have played a key role in ensuring sustainable competitive advantage both at the micro level [29] and at the level of society and states [44]. In [47] argues that as well as the importance of using digital technologies to address sustainability challenges in enterprises, attention should be given to developing business models and organisational improvements based on digital tools to achieve digital sustainability. B [5,48] analysed the benefits of implementing digitalisation for the development of smart manufacturing, including areas such as manufacturing technology and processes, predictive engineering, materials, data, sustainability and resource sharing, and networking. Thus, scholars [8,13,29,49] have analysed the effects of digital technology adoption in different areas of the enterprise.

Empirical analyses [10,11,44] confirm that the availability of digital financial services increases a country's economic growth and worsens its environmental sustainability due to a sharp increase in CO_2. In turn, the work of [50] emphasises that the development of digital finance has a mitigating effect on the environmental inequalities of regions, including by reducing the income gap across regions and converging innovation capacity in green technologies. In addition, the works [6,33,47,51,52] analyse the benefits of implementing e-government and other digital programmes at the government level to promote sustainable and inclusive economic growth, social development and environmental protection.

The articles [33,53] present the formation of a recommendation for designing social sustainability through the use of industrial design to help plan and evaluate digital fabrication projects in the humanitarian and development sectors. In [54], in addition to the social dimension of sustainability, it explores the impact of digital technologies on changing labour processes on horticultural and arable farms, which may have implications for rural development, rural communities, and migrant workers [4]. Analysing the importance of digital transformation, the authors [55] point out the need to take into account the ongoing changes and their possible negative consequences in the policies developed by public authorities.

Based on the above analysis, numerous studies have highlighted the benefits and features of digital inclusion for achieving sustainable development goals in certain sectors (e.g., public administration [51], financial services [45], entrepreneurship [38], agriculture [54], energy [31,32] and others). An important area of research is also the study of the negative impact of digitalisation on the sustainable development of territories, societies and business entities. Therefore, the aim of the article is to identify the relationship between sustainable development and digital transformation by characterising the evolution of key patterns of scientific publications on this issue.

3. Materials and Methods

The study chooses bibliometric analysis as a method that reveals the relationship between sustainable development and digital transformation. This type of analysis is based on mathematical graph theory, clustering and scientific visualisation methods, which makes it widely applicable to different scientific fields. The work [56] argues that the growing popularity of this research method is due to the development of bibliometric software and scientific databases, as well as to the interdisciplinary nature of the relationship between computer science and business.

Based on the structuring of a large volume of metadata of scientific publications, bibliometric analysis allows us to identify the essence of the subject area and its conceptual framework and to justify the evolution of the research area. The research methodology included stages such as data collection and analysis, selection of a visualisation tool, graphical representation of the identified relationships and interpretation of the results obtained.

The above was implemented using the VOSviewer v.1.6.19 software product. The functionality of this programme provides for the creation of visualisation maps of keywords based on co-occurrence data, maps of authors or countries based on the number of citations, etc. In addition, neural network visualisation maps in VOSviewer are displayed in several ways (e.g., by content

criteria, by publication period). In addition, neural network visualisation maps in VOSviewer are displayed in several ways (e.g., by content criterion, by publication period). It is important to emphasise that the size of circles on keyword maps is responsible for the frequency of occurrence of an element in the analysed scientific papers, while its colour is responsible for belonging to a certain cluster. The strength of the connection between elements is characterised by the length of the line between them (a longer line indicates a weak connection between two elements).

An important stage of bibliometric analysis, which ensures its quality, is the selection of the data source and the formation of a relevant sample of publications. The Scopus database was chosen as a data source due to the breadth of its coverage of subject areas such as social science, business, management, economics and computer science. To form the data sample, first, the period of publication activity on the studied subject, namely, from 1990 to 2023, was determined. Second, the type of publication source is limited to journal and conference proceedings. Third, the title, abstracts and their keywords were selected as key patterns of scientific publications. The search results contained, on the one hand, categories such as "sustainable development" or "sustainability" and, on the other hand, one of the terms describing digital transformation (e.g., "digital economy", "digital transformation", "information economy", "virtual economy", "information technologies", etc.). Thus, the studied sample of publications included 9,527 works that met the above criteria, published in the period 1990-2023 and indexed by the Scopus database.

4. Results

Quantitative analysis of the generated sample of research papers showed that there was exponential growth of research in the context of the relationship between sustainable development and digital transformation over the period 1990-2023 (Figure 1).

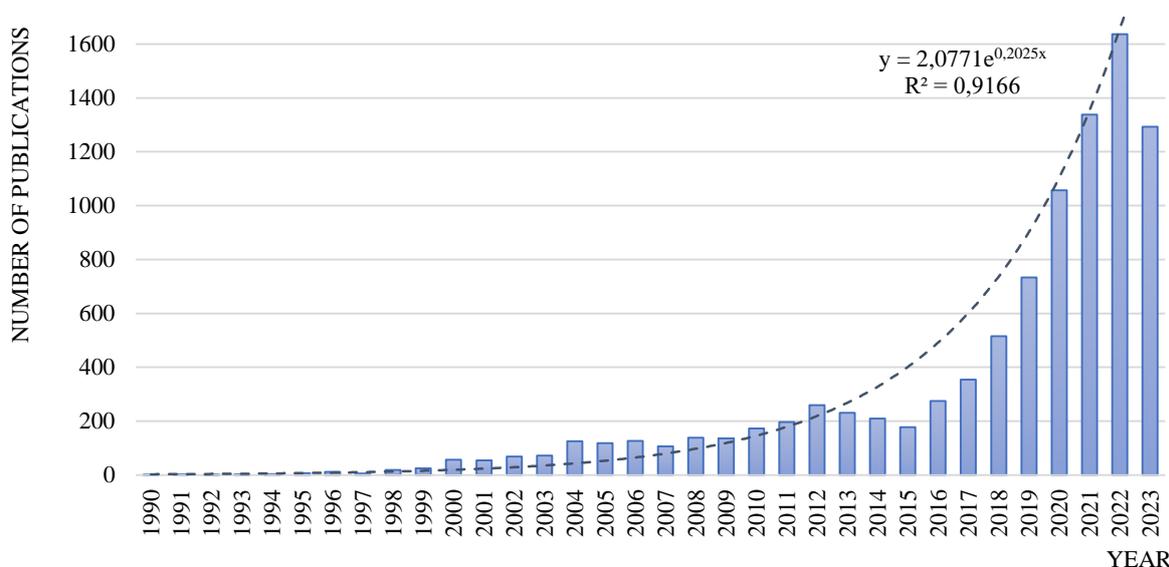The chart displays the exponential trend line with equation $y = 2{,}0771e^{0,2025x}$ and $R^2 = 0{,}9166$.

Figure 1. Dynamics of publications covering sustainable development and digital transformation for 1990-2023.
Source*: own elaboration.*

Taking into account that the data for 2023 are collected for only 2/3 of its part, it can be assumed that at the end of the current year, there will also be a significant increase in the number of publications on the given topics compared to the previous year. On average, the annual increase in publications for the year is 36%.

In addition, quantitative analysis of publications in terms of their countries of origin is also relevant. The size of the circles on the visualisation map (Figure 2) is proportional to the volume of publications indexed by Scopus, and the color of the circles corresponds to the average number of citations of scientific papers. For example, the largest number of publications belongs to authors affiliated with Chinese institutions (1,647 documents of the sample under study), the second place by this parameter is occupied by scientists from the USA (1,164 documents), and the third place is represented by representatives of India (870 documents).

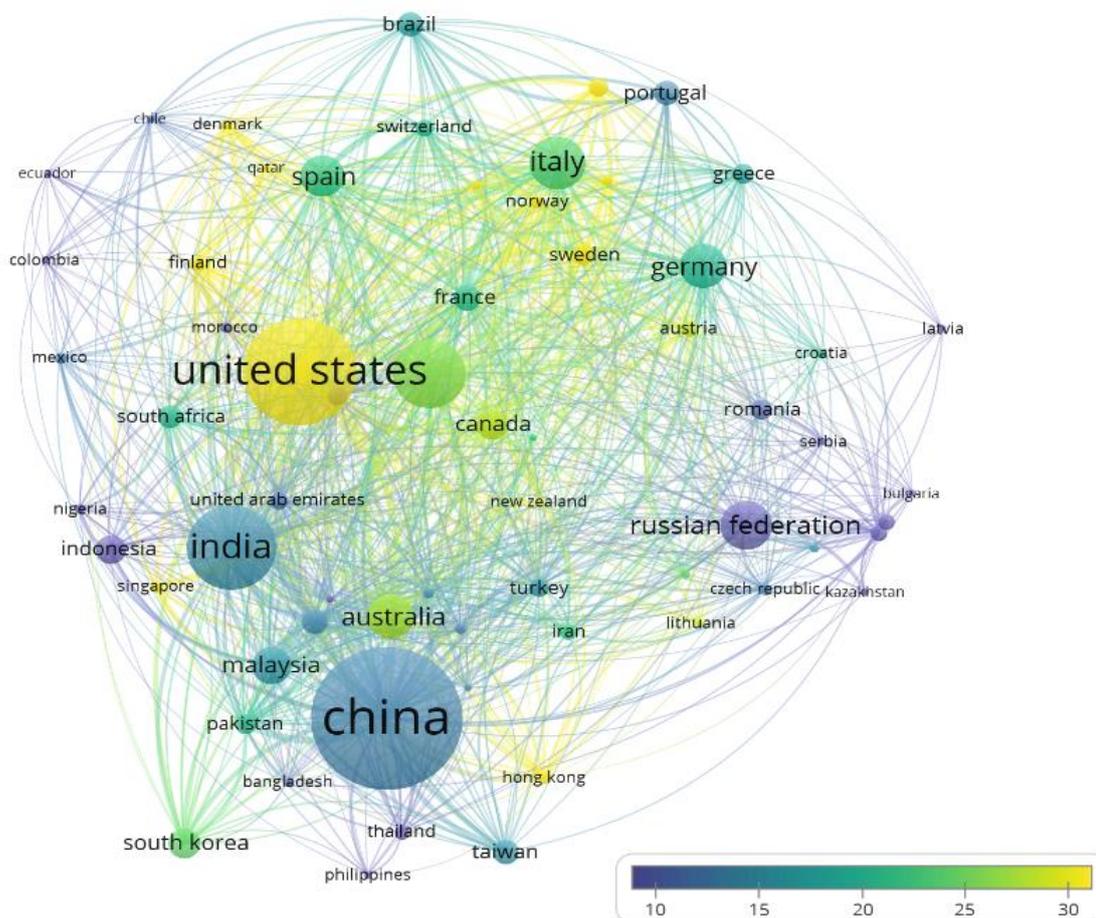**Figure 2.** Countries of origin of publications covering sustainable development and digital transformation for the period 1990-2023.
Source: own elaboration.

However, the superior number of publications by representatives of China and India is inferior to the USA in terms of their citation rate. For example, each article of scientists from the USA is cited 33 times on average, which is more than twice the value of this parameter for

representatives of China and India, the citation of one article of which is 14 times on average. Scientists from Denmark have the highest citation rate, each publication of which is cited in the works of other authors an average of 53 times.

On the basis of the results of the analysis of coincidences and closeness of interrelation of keywords of the selected sample of publications, visualisation neural network maps were constructed (Figures 3 and 4), and five scientific clusters were identified and characterised in the field of research of the abovementioned issues (Figure 3).
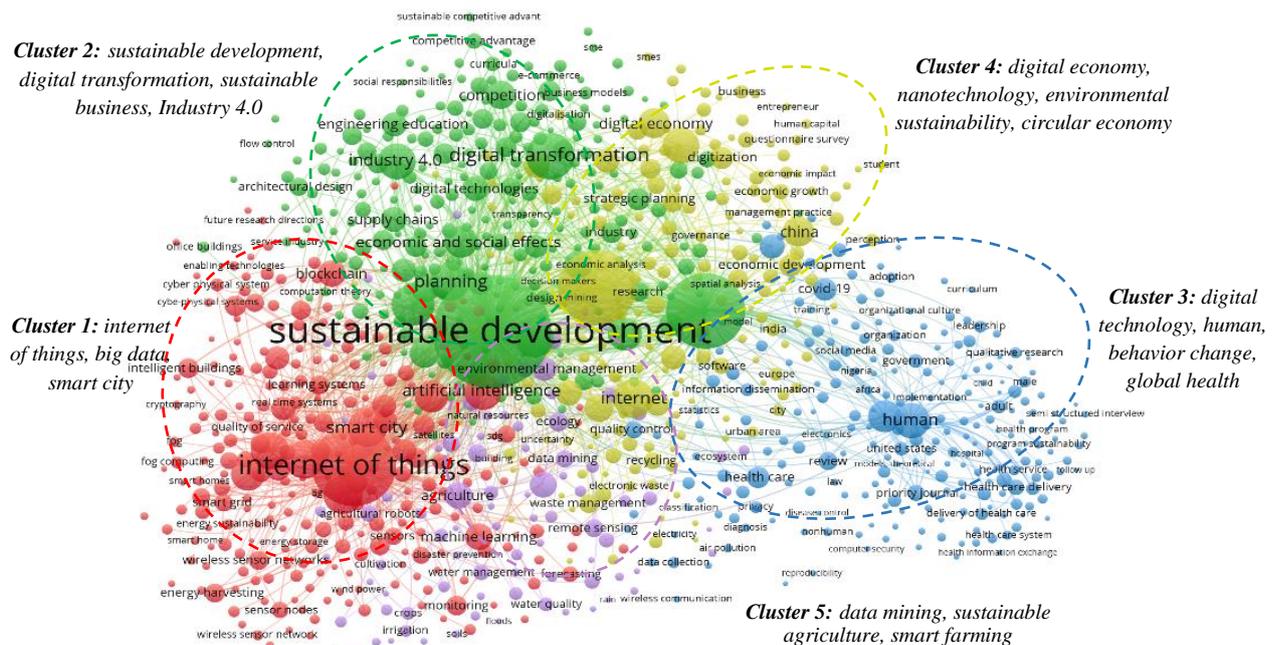
Figure 3. Visualisation map of the bibliometric analysis of publications on research on sustainable territorial development and digital transformation (content aspect).
Source*:* own elaboration.

The first cluster (red colour, Figure 3) contains the largest number of terms (namely, 253 items), among which the following can be distinguished: "blockchain", "artificial intelligence", "big data", "machine learning", "smart city", "intelligent buildings", "energy efficiency", "energy utilisation", "green computing", "sustainable cities", and "urban growth". We should separately mention the keyword "internet of things", the frequency of joint use of which in the studied sample is 2,346, and the strength of connection is 19,247. Taking this into account, this cluster can be named "Technological support of sustainable urban development in the digital economy".

The second cluster (245 items, green colour, Figure 3) combines terms such as "sustainable development", "digital transformation", "Industry 4.0", "sustainable business", "industry", "supply chains", "planning", "economic and social effects", "information management", and "competition". In this cluster, the keyword "sustainable development" has the highest frequency

of co-occurrence is 4,619, while the strength of association is 36,271. Thus, the content of the formed cluster can be characterised by the title "Digital transformation of business as a way to achieve its sustainable development".

The third cluster (230 elements, blue colour, Figure 3) describes the relationship between sustainable development and the digital economy by the following terms: "digital technology", "data science", "human", "education", "health care", "behaviour change", "chronic disease", "environmental factor", "COVID-19", "global health" and others. The main key term in this cluster is "human", the frequency of joint use of which in the studied sample of scientific publications is 453, and the strength of association is 6,516. Thus, the name of the cluster "Problems of the modern stage of information society development in the context of technological breakthroughs" seems logical.

The fourth cluster (185 items, yellow colour, Figure 3) is related to the following categories: "digital economy", "internet", "innovation", "nanotechnology", "economic growth", "circular economy", "carbon emissions", "alternative energy", "recycling", "e-waste", "environmental sustainability", and "natural resource". The keyword "sustainability" has the highest frequency of co-occurrence is 2,049, while the strength of association is 14,798. Thus, the content of this cluster can be characterised by the title "Impact of digital transformation on sustainable consumption and production".

The fifth cluster (86 items, purple colour, Figure 3) covers the following categories: "data mining", "climate change", "waste management", "water management", "ecosystems", "sustainable agriculture", "food safety", "smart farming" and others. The frequency of co-occurrence of the main keyword "agriculture" in this cluster is 2,396, and the strength of association is 257. The title reflecting the content of this cluster could be "Digital transformation in agriculture as a way to achieve sustainable development goals".

Thus, on the basis of the constructed terminological map of categories and the identified most significant keywords related to the issues of sustainable development and digital transformation, it is possible to assert the multidimensionality and crossdependence of the studied areas, as there are numerous connections between the terms, as well as their high occurrence in the studies.

According to the results of bibliometric analysis in the evolutionary and temporal dimension, it can be argued that there are five most significant stages in the development of scientific research related to sustainable development and digital transformation (Figure 4).

The first stage of development was observed until 2014, when most publications analysed general issues of ensuring strategic development of industry using automated information systems and technologies, with the dominant key terms in the publications of researchers being "information technology", "computer software", "information systems", "information dissemination", "societies and institutions", "industry", and "strategic planning". For example, one of the papers [47], published during this period, analyses the determinants of technological development for economic growth. Based on the analysis of panel data for a sample of 29 countries, the author confirms the hypothesis that there is an influence of the quality of education and political institutions on national innovation activity.

before 2014: analysed general issues of strategic industrial development and automated information systems

2014-2016: analysed the impact of using internet, ICT, decision support system on economics, social and ecology

2016-2018: analysed the impact of data mining and technological innovations on sustainable development

2018-2020: analysed the impact of big data, cloud computing, e-learning on sustainable development

after 2020: analysed the pros and cons of digital technologies on sustainable development

Figure 4. Visualisation map of the bibliometric analysis of publications on sustainable development and digital transformation research (evolutionary and temporal aspects).
Source*: own elaboration.*

In the second phase, which took place from 2014 to 2016, the focus of scientists' research shifted to the terms "internet", "decision support system", "information and communication", "economic and social effects", "ecology", "environmental impact", "competition", and "environmental protection". Thus, the publication [57] was devoted to analysing the impact of information technologies on environmental indicators. The authors conclude that a firm's ability to utilise the flexibility of IT technical infrastructure, IT staff skills and IT business alignment allows IT to be integrated into environmental management processes to improve environmental performance, and this IT integration becomes stronger when the firm is more focused on environmental sustainability.

From 2016 to 2018, that is, in the third of the highlighted stages, the dominant key terms were "data mining", "information management", "sustainable development", "commerce", "technological development", "innovation", "life cycle", "recycling", "intelligent buildings", "energy efficiency", and "energy utilisation". One of the works of this period is the work [58], which reveals the relationship between technology convergence, open innovation and the dynamic economy. Based on the principles of deregulation of new enterprises, expansion of human resources, support for new convergent technologies, and increased support for venture capital companies, the author formulated a policy of technological, industrial and economic orientation to mitigate the global economic crisis on the basis of a dynamic economy and sustainable development.

The fourth phase (from 2018 to 2020) is characterised by the predominance of terms - "big data", "network architecture", "cloud computing", "green computing", "data handling", "supply chains", "business development", and "e-learning". For example, the study [59] demonstrates the ability of big data and social media analytics in a participatory web environment to ensure

organisations are profitable and remain sustainable through strategic operations and marketing activities.

The final, fifth stage began after 2020. Based on the results of its analysis, it can be stated that the main terms in the research were the following: "digital transformation", "internet of things", "artificial intelligence", "blockchain", "machine learning", "digital technologies", "digital economy", "circular economy", "smart city", "Industry 4.0", and "metaverse". Thus, one of the most cited works is the publication of the authors [7,60], devoted to the introduction of blockchain technology, its architecture and sustainable supply chains for agri-food products. The experts propose a modular, interoperable and cost-effective blockchain architecture that improves enterprise productivity and supply chain sustainability. In another period-specific publication [61], the authors explore the essence of the meta-universe as a virtual form of smart cities, their possibilities and the challenges of environmental, economic and social sustainability in the future. The results obtained allow the authors to form a conclusion about the disruptive and substantive influence of the meta-universe on the forms of reality reconstruction in the platform urban society.

Thus, summarising the above, we can trace the change of emphasis in scientific publications caused by the development and improvement of information technologies (from the already traditional: "internet", "computer software", "information systems", widespread at the first-third stage (Figure 4) to the growing importance of digital economy tools ("big data", "internet of things", "artificial intelligence", "blockchain", "machine learning") at the fourth-fifth highlighted stages. The widespread application of modern technologies has led to the emergence of new phenomena and directions of scientific research, such as "e-learning", "smart city", "platformized urban society", "metaversion", etc., which determines the importance of simultaneous study of the subject area in the context of the implementation of digital transformations.

5. Discussions

Despite the valuable results of this study, there are some limitations and shortcomings. These studies may not fully objectively reflect the specifics of the development of research topics in particular countries, as the focus is on identifying global trends.

In the publication [61], exploring the potential contribution of modern technologies and the Metaviverse to smart cities from the perspective of their virtual embodiment focuses on the environmental, economic and social goals of sustainable development. It is argued that the embodiment of the Metavieworld concept may increase class social segregation, as people with limited economic or physical capabilities will not have access to the desired technologies. Thus, along with the benefits of digital transformation, researchers point out the factors of the negative impact of digital technologies on sustainable development. However, the bibliometric analysis performed on the relationship between sustainable development and digital transformation does not allow us to confirm or refute the results [61] because it does not describe the functional relationship between the explanatory and explanatory variables. As a result, it is impossible to assess the strength and direction of the relationship between the variables to identify their causality (from a statistical point of view).

According to the work [62], the Scopus database may contain duplicate articles, resulting from journal name changes as well as spelling differences in the spelling of journal names. In this regard, several bibliographic records may correspond to one publication, which leads to errors in identifying citations of publications, authors, institutions, countries and journals. Nevertheless, the original sample of publications was not checked for repetitive records (due to the low frequency of occurrence of this phenomenon).

6. Conclusions

Based on the objective and the results of the study, we can conclude that there is a link between sustainable development and digital transformation. Thus, the empirical data showed exponential growth of research in the context of the relationship between sustainable development and digitalisation (the annual growth of publications on this topic is 36%). It can be assumed that, according to dialectical law, the accumulated quantitative changes will turn into qualitative changes, which will lead to the complementarity and mutual stimulation of these factors.

In this paper, we have performed bibliometric analysis of key patterns of scientific publications on sustainable development and digital transformation. Using VOSviewer software, neural network visualisation maps of keyword matches of publications indexed by the Scopus scientific database from 1990 to 2023 were generated. Five clusters were identified and described according to the content match of keywords of the studied sample, and the presence of the five most significant stages of development of scientific research on sustainability in the context of the digital economy was established.

A comprehensive analysis of the identified research areas has shown that the introduction of digital tools, new methods and ways of data processing are priorities at the international level for the development of individual components of sustainable development. The widespread use of modern technologies leads to the emergence of new phenomena and directions of scientific research, which determines the importance of simultaneous study of the subject area in the context of the implementation of digital transformations.

The materials of the study contribute to a more complete picture of the formation of new trends in scientific research on sustainable development, as well as to the identification of key aspects of ensuring the effective functioning of states, society, and enterprises in today's rapidly changing and increasingly complex conditions. Interdisciplinary studies related to bifurcation in the development of civilisation may be a prospect for future research based on the results of this article.

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