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Topic Mining and Future Trend Exploration in Digital Economy Research

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Abstract: This work proposes a new literature topic clustering analysis framework, based on which the topics of digital-economy-related studies are condensed. First, we calculated the word vector of keywords using the FastText model, and then the keywords were merged according to semantic similarity. A hierarchical clustering method based on the Jaccard coefficient was employed to cluster the domain documents. Finally, the information gain method was applied to estimate the high-gain feature words for each category of topics. Based on the above framework, 23 categories of research topics were formed. We divided these topics into layers of digital technology, convergence innovation and digital governance, and we constructed a three-level digital economy research framework. Thereafter, the current hot spots and frontier trends were derived based on the number and growth rate of the literature. Our study revealed that the research on digital technology, which is the basic layer of the digital economy, has waned. The field related to the integration and innovation of digital technology and the real economy was the current research focus, among which the results with respect to "New Business Forms in the Digital Age", "Circular Economy" and "Gig Economy" were abundant. The problems of the unbalanced development of the digital economy and digital monopoly have strengthened research on digital governance. Furthermore, research on "Regional Digital Economy", "Chinese Digital Economy" and "Data Management" is in its initial stage and is a potential area of future research.

Keywords: digital economy (DE); topic mining; FastText; information gain; hierarchical clustering

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1. Introduction

The Internet ushered in an era of rapid commercialization during the early 1990s. Various new business models, Internet services and Internet enterprises emerged. Thus, the concept of the "digital economy (DE)" was born. Following the outbreak of the international financial crisis in 2008, 3G mobile intelligent terminals emerged, owing to the widespread communication network. New business forms for the DE, such as the sharing economy and platform economy, are growing rapidly. Concomitantly, the development of the DE has shown the characteristics of "mobility". Recently, the empowering role of digital technology has been enhanced, owing to the rise of big data, cloud computing, the Internet of Things (IoT) and artificial intelligence (AI). As digital technology is rapidly penetrating into various industries, the DE has replaced traditional industries as the new driving force leading economic development, and it has become the basis for digital government and digital society [1]. With respect to its strategic importance, the DE has become a key industry around the world, thus being significant for academic research. According to the

China Academy of Information and Communications Technology (CAICT), the total scale of the DE in 47 major countries around the world reached USD 38.1 trillion in 2021, which was 45% of the proportion of GDP. The global DE has shown an expansionary trend with a growth of 15.6% year-on-year [2]. Apparently, DE has become a major driver of global economic growth. There is no unified theory for defining the connotations of the DE yet [3]. Its concept was originally proposed by OECD in the 1990s, i.e., the economic activities that are formed based on the Internet and information and communication technologies (ICT). The G20 Summit in China defined the DE as a series of economic activities using Internet data as the main production factor, besides the effective use of ICT and AI as a carrier. Apart from agricultural and industrial economies, the key resource of the DE is digital information (including data elements). A series of new business models and new economic activities have emerged in the context of DE [4].

Traditional economic theories and regulatory systems are no longer applicable to the virtual and intangible DE. The development of the DE necessitates new economic theories for guidance. With respect to the rapid development of the DE, there are several studies on DE platform construction, industry digitization, digital industrialization, DE governance, and digital technology. Because the world is entering the digital age, it is important to sort out the current research and explore the DE in academic studies to understand the overall economic situation.

Several scholars have conducted bibliometric studies on DE literature, and most of them have employed manual combing or citation visualization based on bibliometric software. The representative studies are as follows. Liu conducted a keyword co-occurrence analysis of the circular economy and digital economy integration literature using VOSviewer software (version 1.6.15) [5]. Both Ge and Yao used CiteSpace software (5.8.R2) to conduct visualization and cluster analysis of the DE literature in China [6,7]. Xu et al. used VOSviewer, SPSS (IBM SPSS Statistics 28) and other software to visually analyze the research status of the DE in China [8]. The current review is mostly based on a qualitative analysis and inductive summary. This makes it difficult to systematically and quantitatively summarize the thematic distribution and hot topics of the current literature research on the digital economy. There is a research gap in that there is no study that sorts out the DE research around the world through the incorporation of objective methods. Other issues are how various research topics of the DE are classified, which topics have matured and which topics have unresolved issues. Addressing these issues is conducive to innovation in the theoretical research of the DE.

This paper proposes a new literature topic clustering analysis framework for theme mining. We collect DE research from around the world from the last five years. We clarify the research content and knowledge structure of the DE by combining the quantitative and qualitative analytical methods. The research hot spots and academic frontiers of DE are sorted out. Accordingly, we can comprehensively grasp the general pattern of DE research. This, in turn, will promote future research on the frontiers of the DE and help traders and authorities utilize the ensuing opportunities.

The remaining content of this paper is arranged as follows: Section 2 reviews related literature results on the DE. In Section 3, we propose the literature topic discovery model. We present the indicators and methods utilized in the framework and describe their advantages. In Section 4, the framework introduced in Section 3 is applied to sort out the DE literature. A total of 23 categories of research themes and corresponding keywords are obtained. In Section 5, by sorting out and summarizing the contents of the literature under various topics, we summarize the DE research into a three-level framework. Further, we identify research hot spots and topics at the forefront. Section 6 presents the conclusions.

2. Literature Review

The DE is a new techno-economic paradigm endowed with rapid technological iterations and rich connotations. The DE is constantly challenging the traditional framework of economic research. Both the theoretical research and scenario practice of the DE are

in the process of evolution. Recently, scholars have expanded their research from the measurement and impact of the DE on industries and society, to its governance issues as well as bibliometric study.

2.1. Measurement of DE Development Level

Measurement of the development level of the DE is conducive to determining the economic situation and regulating industrial development. Certain scholars have measured the DE development level and differences between countries from a macro perspective. Chen et al. calculated China's quality development index of the digital economy in 2010–2019 and analyzed the main factors of digital economy development [9]. Milošević et al. used the Composite I-distance Indicator (CIDI) methodology to create a multivariate indicator as a measurement of digital economy performance. They then assessed and ranked the digital performance of 28 countries/regions in the European Union (EU-28) [10]. Bruno et al. simplified the Digital Economy and Society Index (DESI), a measurement of the digital divide commonly used in European states, to assess the digital divide between countries or regions [11].

Certain scholars have measured the level of development of the regional digital economy. Guo et al. measured the development level of the DE in China's Yangtze River Economic Zones and analyzed the evolution of the DE from the perspective of time and space [12]. Chen et al. constructed a DE development level index system to examine the impact of the DE on regional disparities in a high-quality economic development [13]. Wang evaluated the development of the digital economy in Shaanxi Province in China based on machine learning algorithms [14]. Guo and Liu constructed an evaluation index system of the digital economy development level from four dimensions: digital infrastructure, digital industry, digital application level and digital innovation ability. They distinguished the level of digital economy development in China's eastern and western regions [15].

Certain scholars have constructed a framework for measuring the level of DE development at the enterprise or industry level. Ruiz-Rodriguez et al. constructed a synthetic index of digital development (Enterprise Digital Development Index, EDDI) for countries in the EU and Spanish regions to evaluate the digital divide at the enterprise level [16]. Wibisono proposed a Digital Platform Economy (DPE) index framework and empirically measured the development of the Digital Entrepreneurial Ecosystem in Germany, France and Austria [17]. Lin and Zhao constructed the super-efficiency DEA model of non-parametric estimation and Malmquist index model to empirically analyze the high-quality development efficiency of the digital music industry [18].

2.2. Impact of DE on Green Development

Certain scholars have studied the impact of the DE on green development. For example, Zhang et al. empirically examined the impact of the DE on carbon emission intensity and its effective mechanism. Further, they analyzed the impact of the effect of carbon emission reductions on urban green economic transformation [19]. Shi and Sun examined the impact of the integration of the DE and entity economy on green innovation [20]. Sun and Wu empirically examined the impact of the digital economy on regional carbon emissions and its mechanism of action [21]. Zha et al. also researched whether the digital economy can reduce carbon emissions based on panel data from China's Yangtze River Delta urban agglomeration. It was proved that the digital economy has a significant carbon emission reduction effect [22]. Luo et al. administered principal component analysis (PCA) to evaluate the advancement level of the urban digital economy and employed the number of urban green patent applications to represent green innovation level. They then explored the effect that the digital economy has on green innovation [23].

Certain scholars have focused on the impact of the DE on traditional industry transformation. For example, Wang et al. found that the DE can significantly promote the transformation of industrial structure, owing to the nonlinear characteristic of an increasing marginal effect [24]. From the perspective of agriculture, Zhao and Xu proposed that the

DE can enhance the resilience of the agricultural economy by optimizing its industrial structure [25]. Kan et al. used system GMM (Generalized Method of Moments) to empirically demonstrate that the digital economy can improve the participation and position of China's service industry in the Global Value Chain, and it can promote the upgrading of the Global Value Chain of China's service industry [26]. Tang found that the digital economy of each country (region) has a driving effect on the UK's tourism, with a marginal increasing trend based on empirical evidence in the UK [27].

The mounting risks of data security have posed new challenges to global digital governance. Therefore, DE policies have attracted extensive attention. Meng proposed a platform governing measures such as strengthening public safety regulations and optimizing platform rules to improve the governance of online service transactions [28]. Bai et al. suggested that the coordination of macroeconomic policies, particularly financial subsidy and monetary policies, are conducive to the sustainable development of China's digital economy [29]. Giannone and Santaniello conducted a qualitative content analysis of the following indicators that the European Commission created, which were used to evaluate the EU's digital policies: the Digital Agenda Key Indicators (DAKI), the Lead indicators for DG Connect policy priorities and the Digital Economy and Society Index (DESI) [30].

2.3. Bibliometric Study of DE

Scholars have conducted overall reviews of the DE literature from the perspective of time series, major research institutions, disciplinary distribution and hot topic mining. Rosário and Dias conducted a bibliometric analysis of the works related to digital transformation and sustainable development to uncover the relationship between the two. Digital transformation has a potential contribution to environmental, economic and social sustainability [31]. Liu et al. conducted a bibliometric analysis on the digital circular economy literature in the Web of Science (WOS) database by employing a keyword co-occurrence analysis method with VOSviewer visualization software (version 1.6.15). The relationship between digital technology and the circular economy (CE) was explored, and digital technology was found to have a facilitating effect on the circular economy [5]. Sutherland provided a review of the research related to the sharing economy. Furthermore, the key role played by digital platforms in the sharing economy was explored. His research filled the existing gap in the literature on the relationship between digital platforms and the sharing economy, and it provided direction for future research [32]. Ge et al. conducted a visual analysis and cluster analysis of authoritative literature in the CNKI database. The primary areas of Chinese DE research were found to be big data, digital technology, digital trade and AI [6]. Yao and Yan used keyword co-occurrence and cluster analysis to review four aspects of the digital economy, viz., the connotation and measurement of the DE, digital trade, the economic effects of digital finance and the governance issues of the DE [7]. Xu et al. conducted a review from the theoretical and measurement perspectives of the DE. Based on the analysis of pros and cons of 12 DE indicator systems, they constructed a new indicator system [33].

By combing the above literature, the existing studies were found to be valuable from specific perspectives. There still exists a research gap in exploring the latest hot topics of the DE from a global perspective to reveal the full picture of DE research. If all authoritative DE literature can be objectively analyzed and sorted, it would be significant for the advancement of DE theory innovation.

3. Literature Topic Discovery Model Construction

The authors of [34] proposed a systematic clustering and information-gain-based topic discovery analysis method, which first constructs a word document matrix and then employs Jaccard similarity coefficients to cluster the word document matrix and classify topics according to the co-occurrence relationship of keywords in different documents. However, this method ignores the prevalence of keyword synonymy in the word document matrix, which ultimately affects the effect of topic clustering.

To address this problem, an improved literature topic discovery model is proposed in this study. First, the word vector of keywords in the literature abstract is calculated based on the FastText model. Second, the semantic similarity of keyword word vectors is calculated via the cosine similarity. Then, the semantically similar keywords are merged to obtain a synonymous keyword bag of words. Third, a word document matrix is constructed based on the bag of synonymous keywords, and the documents are clustered. Fourth, the information gain of each keyword in each topic is calculated. The feature words of each topic are extracted according to the information gain value. The overall framework of the model is shown in Figure 1.

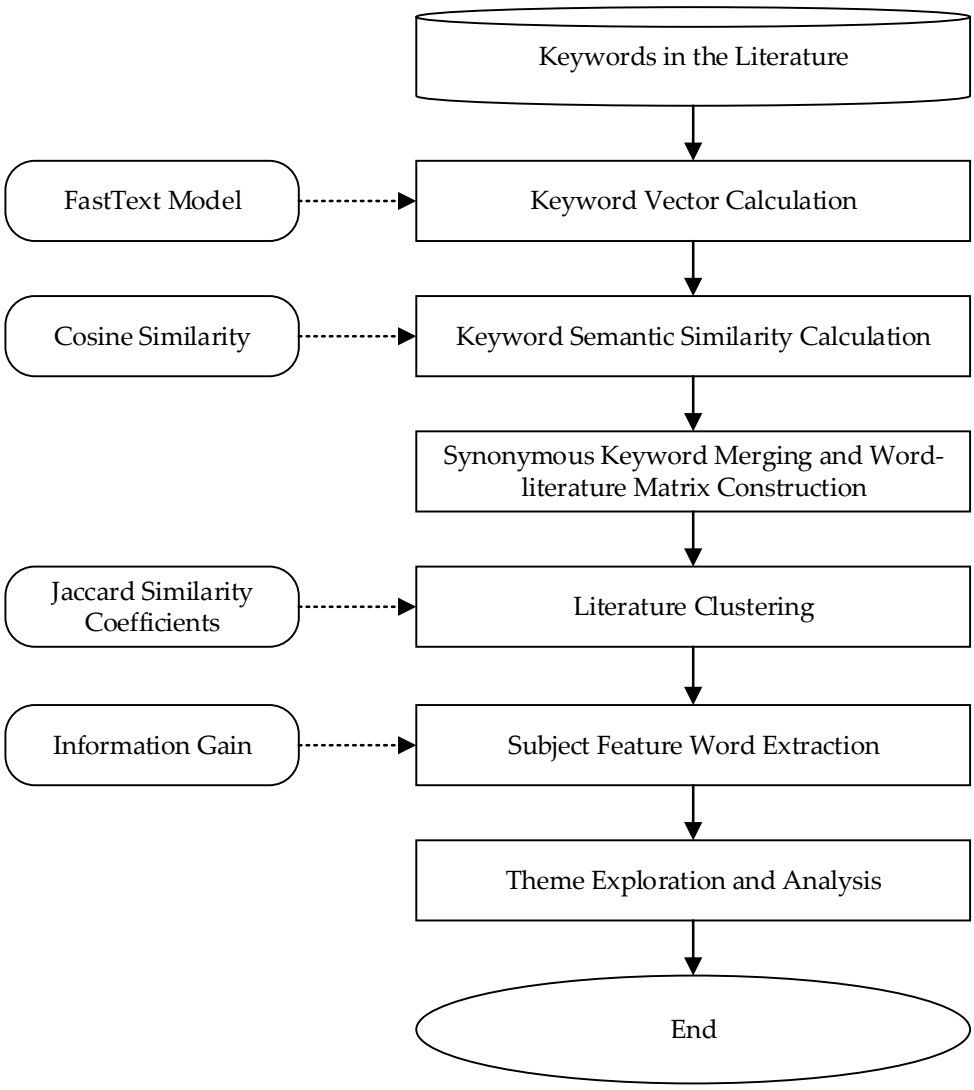

Figure 1. Topic discovery model.

3.1. Keyword Word Vector Calculation and Synonymous Keyword Merging Based on the FastText Method

Word vectors express the correlation and intrinsic connection between two keywords. FastText is an open-source word vector computation and text classification tool obtained from Facebook. It decomposes each word of the input context based on the n-gram format and sums all the word n-grams following the decomposition process with the original word as the semantic information representing the context [35]. In rare word vector generation, the semantics of the word vectors generated by FastText are more accurate and of higher quality than that of alternate methods, such as word2vec. It may effectively solve the problem of individual keywords beyond the training corpus, and it may improve the

merging of semantically similar words of the literature keywords. Therefore, this method can make the clustered subject terms more distinct and thus improve the subsequent topic clustering effect.

The similarity between two keywords is defined as the cosine similarity based on the word vector obtained from the FastText model training sub-word. The formula for calculating the cosine value is shown in Formula (1):

$$\cos(\theta) = \mathrm{sim}(\mathrm{A}, \mathrm{B}) = \frac{A \bullet B}{\|A\| \bullet \|B\|} = \frac{\sum_{i=1}^{n} (A \times B)}{\sqrt{\sum_{i=1}^{n} (A_i)^2} \times \sqrt{\sum_{i=1}^{n} (B_i)^2}} \quad (1)$$

where $\cos(\theta)$ and $\mathrm{sim}(A, B)$ indicate the cosine similarity of keyword A and keyword B. The vector $A = [A_1, A_2, \ldots, A_\mathrm{i}, \ldots, A_\mathrm{n}]$ and vector $B = [B_1, B_2, \ldots, B_\mathrm{i}, \ldots, B_\mathrm{n}]$, where n represents the dimension of the word vector. The range of $\cos(\theta)$ is $[-1, 1]$. A larger value indicates a more consistent vector direction of the two keywords, which implies a smaller gap between the two. Conversely, a smaller value indicates a more inconsistent vector direction of the two keywords, which implies a larger gap between the two. Particularly, when $\cos(\theta)$ takes a value of 1, the two vectors are co-directional and co-linear, indicating that the two keywords have the same word vector.

3.2. Topic Clustering Based on Jaccard Similarity Coefficient

The Jaccard similarity coefficient is a general method used to calculate text similarity in mathematics. It can be employed as a statistic to compare the similarity of sample sets. It is defined as the size of the intersection of sample sets divided by the size of the concurrent set of sample sets. In this work, a larger Jaccard similarity coefficient indicates a higher similarity of documents [36]. Let K_1 and K_2 be the sets of keywords contained in each of the two documents, and the Jaccard similarity coefficient between K_1 and K_2 can be defined according to Formula (2):

$$J(K_1, K_2) = \frac{|K_1 \cap K_2|}{|K_1 \cup K_2|} = \frac{|K_1 \cap K_2|}{|K_1| + |K_2| - |K_1 \cap K_2|} \quad (2)$$

where $|K_1|$ represents the set of keywords of one document, $|K_2|$ represents the set of keywords of another document, $|K_1 \cup K_2|$ represents the set of all keywords contained in these two documents, and $|K_1 \cap K_2|$ represents the intersection of the keywords contained in these two documents.

The advantage of the Jaccard similarity coefficient, when compared with the simple coefficient comparison method, is that keywords that are not contained in both documents are eliminated in the calculation. Therefore, it nullifies the effect of word document matrix sparsity on the similarity of documents to obtain higher accuracy and better clustering results.

3.3. Topic Feature Extraction Based on Information Gain

The topic feature keywords need to be extracted to accurately parse the connotations of the research topics of each category. The subsequent topic condensation is carried out on this basis.

In this work, the information gain method is employed for feature keyword extraction. The importance of a keyword for the corresponding category is measured according to the amount of information, or the information gain, that the keyword brings to the topic. If a keyword carries higher information gain, it implies that it can better distinguish between the topics and reflect its connotation.

Generally, the information gain of a keyword tk to category C is the difference in the information entropy $H(C)$ of category C between the cases corresponding to the keyword being considered and not considered.

The information entropy $H(C)$ of category C when the keyword is not considered is shown in Formula (3):

$$H(C) = -[q_c \lg(q_c) + q_{\bar{c}} \lg(q_{\bar{c}})] = -[\frac{x_1}{x} \lg(\frac{x_1}{x}) + \frac{x_2}{x} \lg(\frac{x_2}{x})] \quad (3)$$

where q_c is the probability of the occurrence of category C, the probability of the occurrence of non-category C, x is the total number of documents, x_1 is the number of documents belonging to category C, and x_2 is the number of documents belonging to non-category C.

Category C's information entropy $H(C \mid t_k)$ in the case of considering keyword k is shown in Formula (4):

$$H(C|t_k) = -\frac{y_1 + y_2}{x}[\frac{y_1}{y_1 + y_2} \times \lg(\frac{y_1}{y_1 + y_2}) + \frac{y_2}{y_1 + y_2} \times \lg(\frac{y_2}{y_1 + y_2})] - \frac{y_3 + y_4}{x}[\frac{y_3}{y_3 + y_4} \times \lg(\frac{y_3}{y_3 + y_4}) + \frac{y_4}{y_3 + y_4} \times \lg(\frac{y_4}{y_3 + y_4})] \quad (4)$$

where y_1 is the number of documents in which keyword t_k appears in category C, y_2 is the number of documents in which keyword t_k appears in non-category C, y_3 is the number of documents in which keyword t_k appears in category C, and y_4 is the number of documents in which keyword t_k appears in non-category C.

Therefore, the information gain of keyword t_k for category C is shown in Formula (5):

$$IG(t_k) = H(C) - H(C|t_k) \quad (5)$$

4. Results

4.1. Data Source and Pre-Processing

The data employed in this paper are sourced from the Science Citation Index Expanded (SCI-EXPANDED) and Social Science Citation Index (SSCI) in the Web of Science database. The retrieval topic is "digital economy", excluding all literature except journal articles and review papers. We collected 4193 documents as the primary data, which were published between 1 January 2018 and 1 March 2023.

The literature without keywords was removed from the data set of 4193 documents, thus leaving the remaining 3776 documents. There were 22,141 original keywords, including duplicate keywords. Because some of the literature keywords had very limited significance to this study, we cleaned these keywords. The steps are given in the following. First, we eliminated symbols such as parentheses and hyphens. Second, we removed keywords that were meaningless to the study, such as pure numbers and special characters. Finally, we removed duplicate keywords. Consequently, a total of 11,247 literature keywords were actually obtained.

The empirical process of this study is described as follows:

1. Jieba was employed to sub-phrase the set of abstract texts from the retrieved documents. The deactivated words were removed from the set of abstract texts after word separation using the HIT deactivation word list. Then, a training corpus was formed.
2. We calculated the word vector of each keyword based on the FastText model and merged the keywords with a high cosine similarity.
3. We clustered the topics based on Jaccard similarity coefficients and calculated the information gain of each keyword to each topic category. The connotation of each topic was condensed according to high-information-gain feature keywords.
4. Current hot topics and future trends were discerned by considering the literature volume and growth trend of each research topic, as shown in keyword document matrix.

4.2. Empirical Research

4.2.1. Keyword Semantic Similarity Calculation and Synonymy Merging

The processed corpus was utilized to train the FastText model to obtain the word vector, and then the semantic similarity of keywords was calculated, which was used to merge semantically similar keywords. Taking the keyword "digital economy" as an example, the results of the top 10 similar words in the training results are listed in Table 1.

Table 1. Semantically similar words and similarity of "digital economy" and "business".

Keywords	Semantically Similar Words and Similarity
digital economy	digital-economy (0.999), economy-driven (0.890), new-economy (0.890), ecotourism (0.889), culture-economy (0.888), sharing-economy (0.882), gig-economy (0.880), economy-specific (0.879), bio-economy (0.879), crypto-economy (0.878)
business	ebusiness (0.997), ibusiness (0.996), business-to-business (0.995), e-business (0.994), business' (0.992), business's (0.991), e-business (0.984), agribusiness (0.984), ibusinesses' (0.980), business-friendly (0.964)

In the next step, a 11,247-row symmetric matrix of semantic similarity between the keywords was constructed, as listed in Table 2 below.

Table 2. Partial keyword similarity matrix.

Keywords	5G Technology	Action Research	Action Design Research	Circular Economy	Circular Bioeconomy	...	Virtual E-Commerce
5G Technology	1.000	0.361	0.374	0.537	0.538	...	0.451
Action Research	0.361	1.000	0.982	0.470	0.471	...	0.235
Action Design Research	0.374	0.982	1.000	0.516	0.518	...	0.256
Circular Economy	0.537	0.470	0.516	1.000	0.999	...	0.496
Circular Bioeconomy	0.538	0.471	0.518	0.999	1.000	...	0.495
...	...	...	...	...	...	...	...
Virtual E-Commerce	0.451	0.235	0.256	0.496	0.495	...	1.000

This matrix was employed to merge the 11,247 keywords. We determined a threshold based on the distribution of word semantic similarity, as shown in Table 2, to decide whether two literature keywords need to be merged. The threshold of semantic similarity merging between the keywords was set at 0.930. If the semantic similarity between two keywords fell within 0.930 and 1.000, the two keywords were merged. We kept 5039 keywords after the merging step.

4.2.2. Topic Clustering Analysis Based on Jaccard Similarity Coefficient

A keyword document matrix of 3776 rows and 5039 columns was constructed based on 3776 works and 5039 literature keywords, as shown in Table 3 below. Each row represents literature, and each column represents a keyword. The number 1 indicates that the literature in the row contains the same word or semantically similar keywords in the corresponding column, whereas the number 0 implies that the literature in the row does not contain the same word or semantically similar keywords in the corresponding column.

Table 3. Keyword document matrix.

Serial No.	Advanced Digital Fashion	China Economy	Digital Economy Platform	Job Vacancies	Regional Digital Economy	Social and Governance Score	...	Spatial Spillover Effect
1	0	0	1	0	1	0	...	0
2	0	0	1	0	1	0	...	0
3	0	0	1	0	1	1	...	0
4	0	0	1	0	1	0	...	1
5	0	0	1	0	1	0	...	0
6	0	1	1	0	1	0	...	0
...	...	...	...	...	...	...	...	...
3776	0	0	0	1	0	0	...	0

The Jaccard similarity coefficients between the documents were calculated based on the keyword document matrix. Then, the hierarchical clustering method was used to cluster the topics of the documents based on the Jaccard similarity coefficients. The advantage of the hierarchical clustering algorithm is that the optimal number of literature clusters can be ascertained visually by drawing a tree diagram, instead of specifying the number of literature clusters in advance. The results are displayed in Figure 2 below.

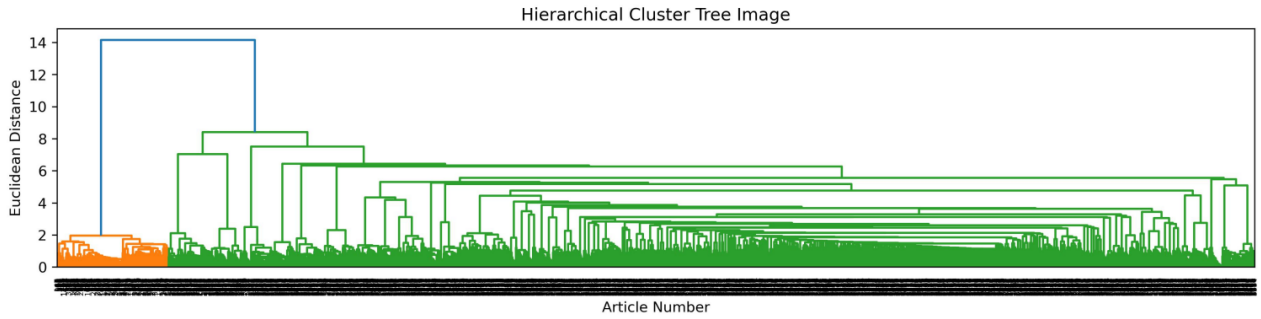

Figure 2. Hierarchical cluster tree image.

We can only explore the laws, characteristics and trends of DE research by choosing a suitable number of literature categories. The distribution of literature would be concentrated for fewer categories, whereas the distribution of literature would be scattered for excess categories. According to the hierarchical cluster tree, a clustering distance threshold of 3.70 is appropriate for classifying the current DE research literature into 23 categories.

4.2.3. Key Feature Word Extraction Based on Information Gain Method

The literature topics were extracted by calculating the information gain of 5039 keywords with 23 categories of topics. The top five keywords in the information gain ranking of each topic are shown in Table 4 below. We determined the core feature words based on the condensed topic connotation and high-information-gain feature words, as listed in the third column.

Table 4. Top 5 high-information-gain keywords.

Series No.	Keywords and Information Gain ($\times 10^{-2}$)	Core Feature Words
1	distributed digital economy system (9.763), emerging digital economy companies (9.736), regional digital economy (9.595), core industries of the digital economy (9.495), Asian digital economy (9.327)	Regional Digital Economy
2	circular economy limitations (4.882), circular economy capability (4.872), construction circular economy (4.852), circular economy framework (4.691), circular economy business model (4.491)	Circular Economy
3	sustainability implications (4.315), sustainability challenges (4.263), sustainability business (4.250), sustainable value (4.002), sustainability transition (3.962)	Sustainability
4	made-in-china 2025 (4.314), china's regional economies (4.296), united states–china relations (4.226), broadband china (4.177), china in transition (4.044)	Chinese Digital Economy
5	innovation model (3.514), regional innovation level (3.443), innovation studies (3.334), financial innovations (3.306), social innovations (3.252)	Innovation Model
6	COVID-19 challenges (3.725), COVID-19 economic crisis (3.682), COVID-19 epidemic influence (3.672), digital COVID-19 vaccination certificate (3.405), pandemic crisis (0.276)	COVID-19 Epidemic Influence
7	tech economy (3.680), modern economy (3.564), gig-based economy (2.700), gig economy issues (1.840), gig economy health interventions (1.795)	Gig Economy

Table 4. *Cont.*

Series No.	Keywords and Information Gain ($\times 10^{-2}$)	Core Feature Words
8	digitalization index (1.955), digital city construction (1.899), business in the context of digitalization (1.583), digital economy platform (0.133), core industries of the digital economy (0.132)	Digitalization
9	urban low-carbon transformation (1.879), digital transformation of manufacturing enterprises (1.626), asian digital economy (0.104), digital economy platform (0.102), core industries of the digital economy (0.101)	Digital Transformation
10	circular industry 4.0 (1.985), industry 4.0 technologies (1.943), smart manufacturing system (0.718), advanced manufacturing industry (0.583), sustainable intelligent manufacturing (0.055)	Industry 4.0
11	ICT (2.395), ICT and EFL (2.372), bright ICT (2.351), ICT4D (2.331), ICT standards (2.259)	ICT
12	social media influencers (2.709), social media analytics (2.690), social media strategy (2.645), social media marketing (2.627), social media technologies (2.518)	Social Media
13	Administration (2.230), 2fa authentication (2.110), Data aggregation (1.153), Data-driven site characterization (0.774), integration contribution (0.530)	Data Administration
14	smart networks (1.449), centralized payment networks (CPN) (1.436), Global Financial Networks (1.436), Alternative Food Networks (1.403), Mobile Network (1.393)	Networking
15	Big data analytical capability (1.892), National big data comprehensive experimental area (1.864), Big Open Data (1.766), Big data network security (1.600), Data privacy (1.311)	Big Data
16	e-commerce model (1.438), awareness of e-commerce (1.405), e-commerce forensic system (1.405), e-commerce adoption (1.369), e-commerce marketing capabilities (1.349)	E-Commerce
17	Political economy approach (2.064), International political economy (2.004), critical political economy (1.986), Political economy of healthcare (1.962), digital political economy (1.803)	Political Economy
18	Digital economy platform (2.987), Digital economy innovators (2.902), Emerging digital economy companies (2.860), sustainable digital economy (2.823), digital economy value chain (DEVC) (2.712)	New Business Forms in the Digital Age
19	Internet studies (1.834), Internet-based treatment (1.834), critical Internet studies (1.808), mobile Internet (1.808), Internet services (1.773)	Internet
20	infrastructuralized platforms (2.674), social-mission platforms (2.625), information platforms (2.569), Supply chain service platforms (2.410), Internet platforms (2.278)	Digital Platforms
21	Digital publishing (2.293), digital Spanish newspapers (2.267), Digital product (2.162), digital game-based learning (2.028), digital and online reading literacy (2.003)	Digital Publishing
22	science and technology studies (2.248), sustainable technology (2.216), Technology Acceptance Model (2.206), Social impact of technology (2.186), science and technology input efficiency (2.158)	Digital Technology
23	Block chain (2.608), blockchain-based evidence (2.608), Blockchain application (2.599), Blockchains (2.590), blockchain security (2.499)	Block Chain

4.3. Key Feature Word Extraction Based on Information Gain Method

The connotations of each category of topics were profiled based on their high-information-gain keywords. These topics cover the components, new business models and social impacts of the DE.

(1) The 1st topic: Regional Digital Economy

The core feature word of the first category is "Regional Digital Economy". After a period of rapid development of the DE, attention shifted to its high-quality development. Regional imbalances in the development of the DE are becoming increasingly evident, owing to the imbalances in the construction and utilization of the infrastructure and the research and development of digital technologies across regions. This is particularly visible in China, which is a vast country. To address this issue, scholars have proposed various comprehensive digital economy index models to assess the regional digital economy development level [37]. Certain scholars have studied the impact of technology, IT infrastructure construction [38], human resources [39] and other factors on the regional digital economy. The DE has shown significant regional heterogeneity in environmental quality improvement, which is beneficial for regional environmental governance [40].

(2) The 2nd topic: Circular Economy

The core feature word of the second category is "Circular Economy (CE)". It has become a social consensus to build a green, low carbon and circular industrial system in the context of advocating green production and green consumption. As a generally accepted term in academic circles, the CE refers to an industrial system that is intentionally designed to achieve recoverable or renewable purposes [41]. CE systems employ renewable energy sources to replace fossil energy. It intends to avoid waste through excellence in the design of materials, products and industrial systems, besides new business models [42]. The integration of digital technologies into the CE has been shown to enable intelligent business processes and products, besides facilitating the stakeholder control of data information generated in the business processes as decision support [43]. The DE has become an important driving force for the CE. However, the application methods of DE technologies for fully exploiting the potential of CE strategies to improve resource efficiency and productivity are still an unresolved issue. The potential integration of the DE and CE (Digital Circular Economy) is of tremendous importance for both theory and practice.

(3) The 3rd topic: Sustainability

The core feature word of the third category is "Sustainability". Digital technologies are integrating the concepts of the CE and sharing economy into new business models and facilitating the redesign of products and value chains. From a sustainability perspective, digital technologies enable improved processes, more efficient data management and fuller resource utilization, which optimize the benefits of sustainable development. However, owing to the increased efficiency, there is also the possibility of a rebound effect [44]. For example, both the form and content of consumption have been explored in the context of the DE, which has increased resource consumption. However, there is a lack of research on the mechanisms by which digital technologies improve resource flows and value creation to influence sustainable development.

(4) The 4th topic: Chinese Digital Economy

The core feature word of the fourth category is "Chinese Digital Economy". The DE is booming in China, making it the world's largest economy following the United States. The investigation of China's digital economy can provide a reference for the low-carbon transformation of countries around the world. High-quality energy development has been proven to be a win–win situation for both economic development and carbon reduction. The DE may accelerate the achievement of China's "carbon offset" goal [45]. Moreover, the bipolar competition between China and United States, mainly in the digital dimension and accompanied by frequent references to the controversy over the decoupling of both nations [46], in 2019, has been scrutinized by the political and economic spheres. The complexity and uncertainty in the US–China relationship will persist, owing to the high interdependence of IT and capital between the two countries, which implies that China's digital economy will generate relentless academic interest.

(5) The 5th topic: Innovation Model

The core feature word of the fifth category is "Innovation Model". The huge innovations brought by the DE are reflected in the change in the traditional industrial organization and operation mode, the reconstruction of the market economy system, the optimization of resource allocation, the integration of digital enterprises and traditional enterprises and the expansion of the consumer market. DE-driven innovation has been investigated by academia and industry. Sultana et al. proposed a systematic process of data-driven innovation [47]. Wang and Cen suggested that the DE promotes innovation efficiency [48]. Xu et al. argued that the impact of the digital economy on innovation presents a threshold effect [49]. Obviously, DE has a positive impact on innovation. In terms of business competition, business model innovation becomes the key path for firms to distinguish themselves, which further clarifies the importance of digital technology [50].

(6) The 6th topic: COVID-19 Epidemic Influence

The core feature word of the sixth category is "COVID-19 Epidemic Influence". The COVID-19 epidemic has severely impacted the global economy, thus resulting in the COVID-19 economic crisis. Concomitantly, the DE is growing rapidly, accompanied by the emergence of new activities such as online shopping, telecommuting, online learning and online social interaction, which have driven the digital transformation of traditional industries [51]. New business models and digital transformation have mitigated the negative impact of the COVID-19 epidemic [52]. Therefore, scholars have scrutinized the interrelationship among the DE, the influence of the COVID-19 epidemic and the global economy. Particularly, they have focused on the changing economic situation and the extent of digital transformation in Asian countries, represented by China [53], to find the factors influencing the development of the DE in those countries. Representative studies, e.g., that by Li et al., have found that Asian countries have transformed business processes through technological innovation, government policies and digital entrepreneurship to advance the digitalization process [54].

(7) The 7th topic: Gig Economy

The core feature word of the seventh category is "Gig Economy". The gig economy is an important component of the sharing economy. It is a new form of labor distribution within the context of the DE, which implies the utilization of the Internet and mobile technology to quickly match the supply and demand of labor. It is becoming a globally popular modern economic model. In the IT-oriented economy, technology and the economy are increasingly integrated, thus driving the modernization of the economy. The algorithmic management model of such labor platforms provides freelancers with highly flexible, autonomous and diverse forms of work. The drawback, however, is that it can entail low wages, social isolation, overwork and other problems. Human rights issues and regulatory problems emerging from the gig economy have been considered by scholars [55].

(8) The 8th topic: Digitalization

The core feature word of the eighth category is "Digitalization". Digitization is the use of digital technology to transform specific businesses and processes to reduce costs and increase efficiency. Complex data, information and knowledge in the physical world have been transformed into computer-identifiable digital information, and then data models have been built to profoundly reshape the global economy. This has brought tremendous changes to the agriculture, manufacturing and service industries. Digitization has also affected the labor market. Although there is a trend of machines replacing human labor for routine tasks, the digitization of industries has increased the demand for new occupations around new production and consumption patterns and digital skills [56]. Owing to the disruptive transformation of traditional industries by digitalization, the impact of digitalization on socioeconomic institutions, the obstacles that digitalization will face in introducing traditional industries, and the possible role of government in the digitalization process are all areas of tremendous interest for academic research [57].

(9) The 9th topic: Digital Transformation

The core feature word of the ninth category is "Digital Transformation". Digital transformation is a high-level transformation based on digital conversion and digital upgrade, which impact the core business of companies and create new business models. Digital transformation is particularly important in the manufacturing industry, owing to the complexity of the value chain creation process of manufacturing companies. In the context of the deep integration of the digital economy and green development, the digital transformation of the manufacturing industry becomes an inevitable path to achieve the goal of carbon peaking and carbon neutrality, and hence to promote high-quality economic development. As the main body of China's entity economy, the effect of digital transformation in the manufacturing industry is not significant [58]. Therefore, it is important to remove obstacles in the digital transformation of the manufacturing industry and to explore methods to lead high-level digital transformation.

(10) The 10th topic: Industry 4.0

The core feature term of the tenth category is "Industry 4.0", or the fourth industrial revolution. Following the German proposal for Industry 4.0 in 2013, the fourth industrial revolution, with advanced digital technologies such as the IoT, big data, robotics and AI as the main drivers, is globally spreading with unprecedented momentum [41]. Digital technology, knowledge and information, as the key production factors, are gradually becoming the main battlefield of the fourth industrial revolution. Integrating key digital technologies in the fourth industrial revolution is conducive to building competitive advantages for industrial enterprises in terms of production technology, financial performance, market expansion, supply chain management, product lifecycle management, workforce empowerment and business models. Accordingly, scholars have studied the production model, barriers and challenges, and supply chain management of Industry 4.0 in the context of the DE. Among them, the integration effect of Industry 4.0 and the circular economy is of tremendous importance for current research.

(11) The 11th topic: ICT

The core feature word of the eleventh category is "ICT". In the digital age, the ICT industry has begun a new round of expansion and is developing in synergy with alternate industries. Two components of the digital economy are digital industrialization and industrial digitization, the former of which is the ICT industry with smart terminals, servers, 5G, cloud storage and optical modules as core sub-industries. As a core driver of industry digitization, ICT has had a profound impact on fields such as finance, manufacturing, the medical industry and the tourist industry. Several studies on ICT have included the positive impact of ICT industry development on economic growth in different regions, such as China [59], Greece [60] and ASEAN countries [61], and the impact of ICT industry development on the income of different categories of self-employed people.

(12) The 12th topic: Social Media

The core feature word of the 12th category is "Social Media". The DE has given rise to new forms of consumption, such as digital content, digital goods and virtual consumption. Social media is booming as an important communication platform for digital products. Digital consumers extensively engage in social platforms, making them a medium for measuring consumer engagement and providing feedback on public opinion about products and brands [62]. Therefore, it has become a challenge for marketers to use public opinion for the diffusion of marketing content to build a mega digital brand. Accordingly, the study of the attention economy based on social media platforms has become an important area of research. Representative results include the concept of the "data attraction model" proposed by Liang [63]. Giraldo-Luque et al. revealed the dichotomous relationship between the social media usage time of college students and monopolistic social media demand [64].

(13) The 13th topic: Data Management

The core feature word of the 13th category is "Data Management". The data dividend is accompanied by the serious challenge of data risk. Big data has generated huge business value, though it brings the risk of data misuse. There have been incidents of user data leakage and misuse and cyber-attacks on databases. Data management, being a fast-growing field, has no mature policy system or technical support. Data security cannot be separated from the regulatory role of the state in the digital market, and certain studies have proposed data agglomeration management methods [65] and two-factor data authentication methods [66] to increase the security of data management.

(14) The 14th topic: Networking

The core feature word of the 14th category is "Networking". The DE has strengthened the interconnection of countries in terms of communication, trade, production, supply and even religion, thus further promoting globalization. The original urban network structure may be reshaped under the influence of the DE, as evidenced by an empirical study on the development of high-quality integration in the Yangtze River Delta in China [67]. Besides its impact on the spatial distribution of urban networks, the DE has given rise to global financial networks (GFN) [68], Alternative Food Networks (AFN) [69], global communication networks and global production networks (GPN) [70].

(15) The 15th topic: Big Data

The core feature word of the 15th category is "Big Data". The literature on this topic focuses on the integration and application of big data in the digital era. Being a product of information technology development, big data initiated from the field of computing and then gradually extended to the field of science and business. Entering the era of the DE, data is slowly becoming a new production factor that drives economic and social development. Big data has become one of the important productivities of the digital economy. Fully tapping the potential of big data to enhance industrial effectiveness is an essential approach for developing new dynamics of innovation and contributing to the high-quality development of the economy. Studies have shown that big data plays a moderating role in the decision making and implementation of circular supply chain solutions, which helps to achieve better environmental, social and economic benefits [71]. However, it brings numerous risks and challenges, primarily in the area of data management [72].

(16) The 16th topic: E-Commerce

The core feature word of the 16th category is "E-Commerce". Digital technology is gradually changing the existing structure of the global economy, thus leading to the growth of the e-commerce industry. E-commerce is a business activity centered on the exchange of goods by applying information network technology. According to the McKinsey Global Institute, most cross-border transactions in 2016 included a digital component. E-commerce is emerging as one of the key competitive areas of the digital economy. With respect to building a competitive advantage in e-commerce, certain scholars have argued that digital infrastructure, localized innovation models and advanced digital payment methods have played a positive role in promoting China in the context of lagging Internet penetration. However, China has not yet been as successful as the United States in B2B e-commerce [73]. The rise of e-commerce has sparked certain discussions about national commerce policies, including how to internationalize firms under the conditions of global e-commerce policy fragmentation, and about methods to develop policies to promote broader e-commerce participation.

(17) The 17th topic: Political Economy

The core feature word of the 17th category is "Political Economy". Digital technologies have changed people's lifestyles, besides significantly impacting the political economy. Digital technology has driven the financialization of the economy, cross-border capital flows and the transformation of consumption patterns. Furthermore, the content, source, storage

and application value of data have been determined by economic, political and social factors. As data and digital technologies gradually become increasingly important elements in economic activities, new regulatory approaches, institutions and organizations are needed for macro-regulation to avoid problems such as data monopolies and information crimes.

(18) The 18th topic: New Business Forms in Digital Age

The core feature word of the 18th category is "New Business Forms in Digital Age". New business forms are new industrial organization forms derived from existing economic activity fields in the context of the DE via the three means, viz., industrial integration, industrial differentiation and industrial networking [74], which are of great significance to promoting the transformation of and upgrading traditional industries and advancing high-quality economic development. The online service industry relies on digital platforms to realize the innovation of service models. The digital transformation of the entity economy has enhanced the supply capacity and production efficiency of enterprises and has made significant contributions to the sustainable development of energy conservation and emission reductions. The newly emerged gig economy and sharing economy have provided abundant employment opportunities and have overturned the supply mode of the labor market. All of the above instances are representative components of new business forms in the digital age. Moreover, the application of the DE in business has led to the emergence of new digital economy enterprises, such as Alibaba, Airbnb, Uber, etc., which have become indispensable players in new business forms.

(19) The 19th topic: Internet

The core feature word of the 19th category is "Internet". Recently, the Internet has had a significant impact on social and economic aspects around the world. It is progressively being employed in various areas of digitalization, such as online diagnosis and treatment, remote working and distance education. In the era of global connectivity, digitalization and the Internet are inseparable. To a certain extent, the DE is essentially the Internet economy. The Internet is an indispensable element of the digital revolution [75].

(20) The 20th topic: Digital Platform

The core feature word of the 20th category is "Digital Platform". Economic activities have been reorganized based on platform ecosystems [76], thus overturning the traditional ways of value creation and value distribution. Digital labor platforms have innovated the form of human capital supply, leading to the emergence of the gig economy [77]. Digital media platforms have enriched participatory media content production in China. The sharing economy has gradually flourished on the basis of digital platforms, gradually covering all aspects of people's daily lives, such as shared travel, household services and accommodation. Digital platforms have altered consumption patterns, improved resource utilization and increased employment. However, the social impact of the platform economy brings the challenge to policy makers of keeping the platform economy's development in a healthy and orderly manner. The diversity of platform economy patterns in each country requires policy makers to tailor policies according to local conditions, which is the domain of platform regulation.

(21) The 21st topic: Digital Publishing

The core feature word of the 21st category is "Digital Publishing". Digital publishing is a product of the integration of the publishing industry and digital technologies, e.g., media technologies, network technologies and display technologies [78]. It has undergone a disruptive change, from early electronic publishing (e.g., e-books and digital newspapers) to content production, reproduction and dissemination inspired by ICT. The prevalence of digital products and digital content has extended to the field of education. Certain teachers have attempted to use digital games as teaching tools to increase students' motivation for learning [79]. However, the widespread diffusion of digital alternatives still needs to be based on measuring and considering issues such as the accessibility and acceptability of digital resources, the quality of publications and intellectual property.

(22) The 22nd topic: Digital Technology

The core feature word of the 22nd category is "Digital Technology". Digital technology innovation is the core driver of the DE. Employing digital technology to achieve cross-border integration increases access to the factors of production, reduces transaction costs and is a necessary condition for the industry to achieve high-quality development. The trend is to integrate digital technology with the entity economy to maximize the value of data. Digital technologies have facilitated the digital transformation of most industries. Smart agriculture [80], high-end equipment manufacturing (HEM), digital finance, the tourist economy and digital treatment are typical new forms of activities arising from digital transformation. However, digital technology innovation can also be constrained by institutional, infrastructural and sociocultural factors. Studying the social impact of digital technologies facilitates the efficiency of technological innovation.

(23) The 23rd topic: Block Chain

The core feature word of the 23rd category is "Block Chain". This topic focuses on the application of block chains in the digital age. Block chains and the digital economy are closely related. First, a block chain is a distributed ledger technology with the feature of decentralized storage and management of information. It ensures the security and immutability of data using cryptography, which can guarantee the security and traceability of data in the development of the DE. For example, a transaction content protection system based on ethernet technology can prevent intelligent forgery and hacking [81]. Xia et al. also pointed out that block chains are effective in addressing privacy protection and data security issues [82]. Moreover, as one of the infrastructures of the DE, block chains can reconstruct a practical financial service system [83].

We conducted a comparison with the previous method proposed in [34]. In this comparison, we employed the same Jaccard similarity coefficient for topic clustering and extracted the keywords of each topic. We found that there are a large number of synonyms among the topic keywords obtained with the previous method. This makes it difficult to condense the research topics because the keywords are redundant and cannot adequately represent the theme. There is no significant difference in the information gain values across keywords. The topic keywords extracted with the previous method are shown in Table 5.

Table 5. Partial topic keywords extracted with the previous method.

Series No.	Keywords and Information Gain ($\times 10^{-2}$)
1	digital economy (9.977), digital economy act (9.949), digital economy era (9.949), regional digital economy (9.949), digital economy act 2017 (9.035)
2	circular economy (4.087), circular economy and waste (4.079), circular economy limitations (4.079), regional circular economy (4.079), the circular economy (4.071)
3	sustainability (4.558), self-sustainability (4.543), ecological sustainability (4.527), sustainability implications (4.527), sustainability orientation (4.527)
4	China (3.958), China dream (3.925), China–US (3.925), US–China (3.925), China's regional economies (3.909)
5	innovation (4.238), app innovation (4.207), exploitative innovation (4.207), IT innovation (4.207), national innovation (4.207)

Comparing Tables 4 and 5, it can be seen that the new model merges a large number of synonyms, making the theme keywords present more topic connotations to enhance the effect of theme condensation.

5. Research Framework of Digital Economy and Exploration of Research Trends

5.1. Digital Economy Research Framework Construction

By sorting out and summarizing the contents of the literature under various topics, we summarized the DE research into a three-level framework. This framework is shown in Figure 3 below.

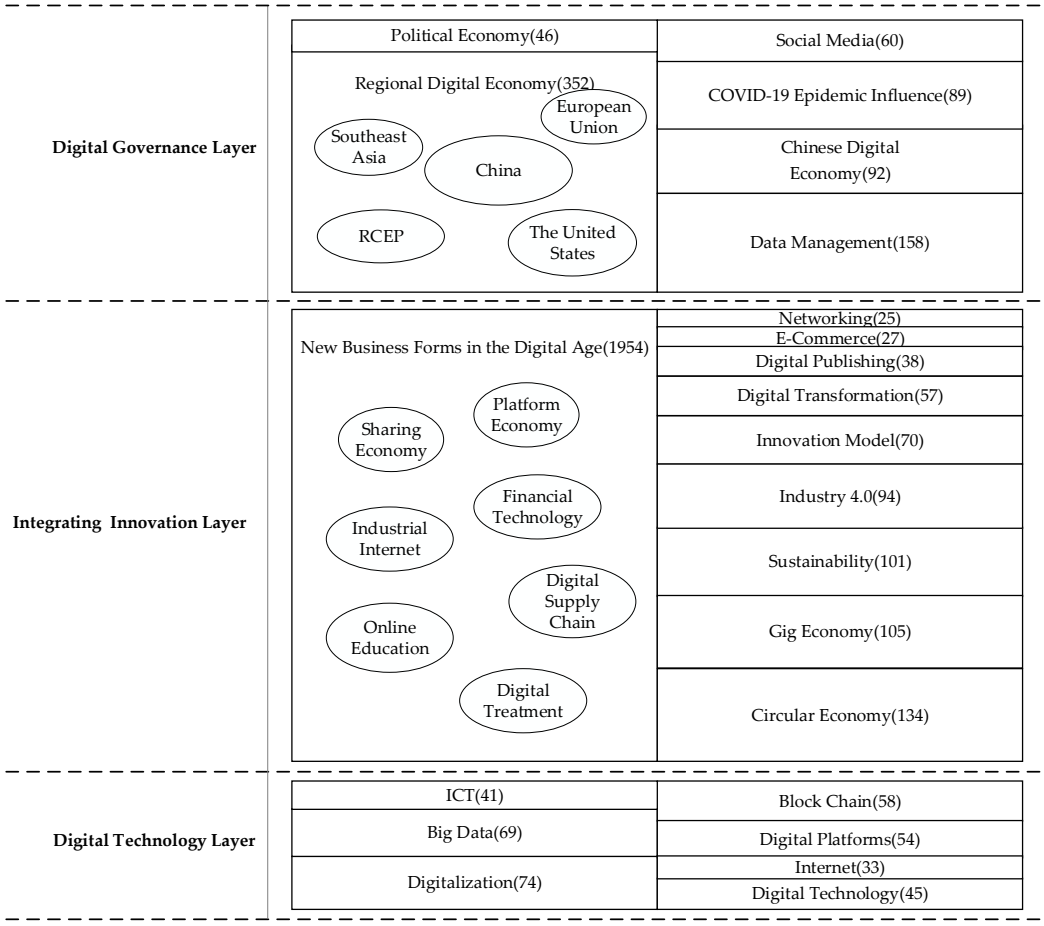

Figure 3. Research framework of digital economy.

The first level is the digital technology layer, in which research topics such as ICT, Big Data, Internet, Digital Technology, Block Chain, Digitization and Digital Platforms are included. The digital technology layer includes research on IT, which can parse and process digital information, and the carriers of the market organization, which deliver the digital information, such as the Internet and digital platforms.

The second level is the integrating innovation layer, which includes the topics of CE, Sustainability, Innovation models, Gig Economy, Digital Transformation, Industry 4.0, Networking, E-Commerce, New Business Forms in the Digital Age and Digital Publishing. The integrating innovation layer intends to explore the new economic activities and business models resulting from the innovative integration of digital technologies and the traditional real economy [4]. Among them, the scholarly achievements of "New Business Forms in the Digital Age" topic are abundant, including the business models and impacts of new industries, such as the sharing economy, platform economy, financial technology and online education. These new industries are disrupting the labor market and product market patterns, thus creating huge business value and employment opportunities.

The third level is the digital governance level, which includes research topics such as Regional Digital Economy, COVID-19 Epidemic Influence, Social Media, Data Management, Political Economy and Chinese Digital Economy. This research explores the new paradigm

of institutional systems in the context of the DE, intending to solve the digital governance problems arising from macroeconomic governance and legal regulations. Research on "Regional Digital Economy" is plentiful. This topic focuses on the measurement of the DE development level and digital transformation paths or strategies of economies in countries or regions, which include the RCEP, European Union, rural and urban China, the United States, Southeast Asia and Pakistan.

The research framework of the digital economy consists of the "Digital technology layer", "Integrating innovation layer" and "Digital governance layer". The scope of research on the DE extends from the micro level of technology to the macro level of society, the economy and culture. The three layers of the DE research framework are interrelated and progressive. Digital technologies such as the Internet, block chains and big data exceed the boundaries of traditional industrial connotations. This detaches the innovation process from the linear rule of knowledge accumulation to application [84], thus making product and service innovation more flexible. Therefore, digital technology is the basis for integrating innovation. Concerning the next layer, the process of integrating innovation is obstructed by traditional industrial transformation barriers, cultural identity and environmental governance. New economic activities generate novel elements of traditional institutional systems and give rise to new economic paradigms and theories of the political economy. New institutional systems that are designed to address digital governance issues, in turn, influence the application of digital technologies and the process of integrating innovation.

5.2. Exploring Hot Topics and Trends in Digital Economy Research

To compare the trend of research and development topics within each level of the DE, we calculated the volume of publications and the average annual growth rate of each topic over the past 5 years, as shown in Table 6. Because the volume of publications is available only for 3 months for 2023, the average annual growth rate was calculated based on the number of publications from 2018 to 2022.

Table 6. Number of articles published and average annual growth rate of digital economy by topic.

Year	2018	2019	2020	2021	2022	2023	Total Number	Percentage	Growth Rate
Total	**237**	**355**	**488**	**864**	**1626**	**206**	**3776**	**100.00%**	**61.84%**
Digital Technology Layer	**24**	**46**	**62**	**89**	**135**	**18**	**374**	**9.90%**	**54.00%**
Digitalization	3	7	7	16	34	7	74	1.96%	83.48%
ICT	1	5	3	12	18	2	41	1.09%	105.98%
Big Data	8	5	13	14	24	5	69	1.83%	31.61%
Internet	5	4	11	6	7	0	33	0.87%	8.78%
Digital Platforms	5	9	8	11	20	1	54	1.43%	41.42%
Digital Technology	2	7	8	11	15	2	45	1.19%	65.49%
Block Chain	0	9	12	19	17	1	58	1.54%	23.61%
Integrating Innovation Layer	**172**	**254**	**352**	**593**	**1094**	**140**	**2605**	**68.99%**	**58.81%**
Circular Economy	6	10	14	36	56	12	134	3.55%	74.79%
Sustainability	5	5	12	31	42	6	101	2.67%	70.24%
Innovation Model	6	7	12	15	28	2	70	1.85%	46.98%
Gig Economy	8	14	15	29	32	7	105	2.78%	41.42%
Digital Transformation	2	2	3	14	29	7	57	1.51%	95.14%
Industry 4.0	3	10	11	23	43	4	94	2.49%	94.57%
Networking	1	7	3	4	9	1	25	0.66%	73.21%
E-Commerce	0	2	2	11	11	1	27	0.72%	76.52%
New Business Forms in the Digital Age	136	191	273	422	834	98	1954	51.75%	57.36%
Digital Publishing	5	6	7	8	10	2	38	1.01%	18.92%

Table 6. *Cont.*

Year	2018	2019	2020	2021	2022	2023	Total Number	Percentage	Growth Rate
Digital Governance Layer	**41**	**55**	**74**	**182**	**397**	**48**	**797**	**21.11%**	**76.40%**
Regional Digital Economy	5	16	16	65	218	32	352	9.32%	156.96%
Chinese Digital Economy	5	6	5	24	49	3	92	2.44%	76.93%
COVID-19 Epidemic Influence	0	0	11	27	48	3	89	2.36%	108.89%
Social Media	7	7	8	21	15	2	60	1.59%	20.99%
Data Management	16	19	26	38	52	7	158	4.18%	34.27%
Political Economy	8	7	8	7	15	1	46	1.22%	17.02%

To compare the year-to-year growth trend of each research level, the year-to-year growth rate was calculated, as displayed in Figure 4.

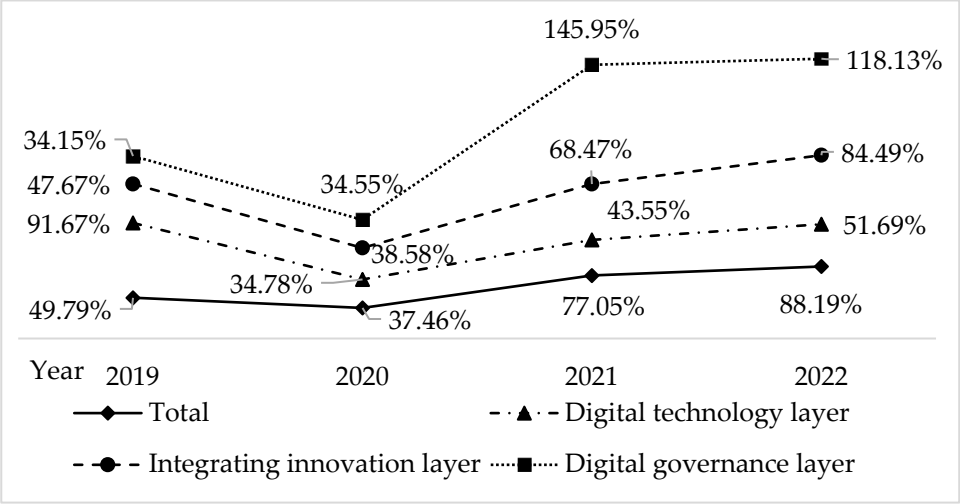

Figure 4. Annual growth rate of publications by layer.

The average annual growth rate of DE publications in the past 5 years is 61.84%. The growth rate was relatively low from 2018 to 2020, whereas the growth rate increased significantly from 2021 to 2022, indicating continuous enthusiasm for the DE.

From a hierarchical perspective, the highest growth rate is observed in digital governance research, particularly the topic of "Regional Digital Economy". Because the DE is currently undergoing a rapid development phase, it is important to consider the macro impact of the DE on politics, the economy and society. Focusing on digital governance is necessary for the high-quality development of the digital economy. We modestly predict that digital governance will become the future research frontier of the DE.

The integrating innovation layer is the current research focus, having the largest number of articles and a high growth rate. The percentage of articles on "New Business Forms in the Digital Age" reached 51.75%, indicating that new economic activities driven by digital technology and supported by data elements have received global attention. The current research focus has shifted from the study of digital technology to the integration and innovation of digital technology and entity economy. The rapid growth of "Digital Transformation" and "Industry 4.0" reveal that the digital transformation of industrial enterprises is a frontier hot spot for the integrating innovation layer.

Digital-technology-related research has the lowest but stable growth rate. The number of articles issued recently is also lower, accounting for only 9.90% of the total, which indi-

cates that, as digital economy research extends to the application level, digital technology as fundamental research of the DE eventually matures.

6. Conclusions

The DE research has gained a global surge in recent years. This work analyzes the 3776 DE-related papers in the WOS core collection published in 2018−2023. FastText word vector calculations, the semantic similarity merging method and the hierarchical clustering method based on Jaccard similarity coefficients were applied in the innovative bibliometric method designed in this paper to classify the above papers into 23 categories. On this basis, a three-level DE research framework was constructed. A quantitative analysis based on the growth rate of literature volume and publication volume revealed the focus of current works and future trends related to the DE. The conclusions are given as follows.

From the perspective of the research framework, DE research can be classified into the layers of digital technology, integrating innovation and digital governance. The digital technology layer forms the basic research of the DE. The topic connotation analysis showed that technologies such as the Internet, big data, and block chains have been extensively employed in diverse fields. Previous research has focused on the impact of digital technologies on the economy or enterprises, whereas research on digital technologies has begun to decline. Popular research topics for the DE include New Business Forms in the Digital Age, CE and Gig Economy at the integrating innovation level, and Regional Digital Economy, Data Management and China's Digital Economy at the digital governance level. The former explores a series of new economic activities derived from the application of digital technologies and is in a booming stage with an intense research activity and literature growth rate. The latter is concerned with the impact of digital technology applications on macroeconomics, politics and culture, with the highest literature growth rate, which is the future research trend.

In terms of specific research topics, first, the impact of the DE on green development has received much attention. The relationship among the DE and CE, sustainability and carbon emissions are frequently being investigated. Essentially, all these topics fall under the scope of green development. The global problems of energy shortage, resource waste and climate change have been a focus in recent research. Digital technology will reshape the value chain. However, the creation of new businesses in the DE brings certain negative impacts on the environment, such as high energy consumption and high emissions from data centers. The coordinated development of the DE and green economy can promote mutual transformation and upgrading. The sustainable development of the economy cannot be achieved without digitalization, whereas the green economy can open a niche space for the further development of the DE. There is an inevitable mutual need relationship between the DE and green economy. Therefore, the green digital economy may become the future trend for the global economy.

Second, the digital transformation of the manufacturing industry is crucial for the sustainable development of the DE. Compared with the alternatives, the transformation of the manufacturing industry, which is an urgent necessity, is more difficult. The fourth industrial revolution is sweeping the world with unprecedented momentum. Traditional manufacturing companies can enhance the competitiveness of their products in the market, thus improving their value chain status by integrating with the DE. Integration with the digital industry has become a trend for traditional manufacturing enterprises to seek survival and development.

Third, the digital transformation of Chinese manufacturing enterprises has received global attention. As the world's most populous country, China proposed the goal of Made in China 2025. This goal will accelerate the development of China's DE and the digital transformation of its manufacturing industry. China's digital transformation experience can serve as a guide for developing Asian countries. Concomitantly, China's huge manufacturing industry with its low level of digitalization will influence the global

industrial landscape, following its transformation from a heavy industry producer to a smart manufacturing and high technology nation.

There are some limitations to this study. The keyword extraction method can be further optimized. In the future, we will build a domain dictionary in the field of the digital economy. The dictionary will contain specialized terms, common vocabulary, acronyms, etc., of the digital economy. Using this dictionary for keyword extraction can improve the accuracy of keywords and reduce the interference of irrelevant words. In addition, supervised learning methods such as neural networks are proven to be effective for keyword extraction. We will try different deep neural network architectures and feature extraction methods.

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