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Goran Buturac

Methodological Development of Digital Economy Indices: A Review and Agenda for Future Research

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**Methodological Development of Digital Economy Indices:
A Review and Agenda for Future Research**

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Methodological Development of Digital Economy Indices: A Review and Agenda for Future Research

Abstract:

This article aims to expand our understanding of the methodological development of digital economy indices and determine the importance of their application in scientific research. As research methodology, a systematic literature review is applied. Scholars' increased interest in this topic has been particularly pronounced in the last few years (after 2017). Research on digital economy indices is regularly conducted and is constantly enhancing with the constructions and implementations of new methodological approaches. Identified shortcomings and advantages of a particular index of the digital economy not only facilitate the selection and employment of appropriate indices in upcoming research, but also enable a high-quality analysis of the results obtained. Besides the analysed shortcomings and advantages, the chronological overview of the development of digital economy indices contributes to their methodological improvements in upcoming research. In addition to insight into existing results, the review of empirical findings reveals insufficiently researched topics. Finally, the outcomes demonstrated in this study might be a sound basis and motivation for achieving new contributions in future scientific papers.

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Keywords: digital economy indices, methodological development, research agenda

JEL classification: O33

1. Introduction

Using digital computing technologies, the digital economy finds its application in numerous economic sectors. Online business interactions contribute to market transparency and efficiency and ultimately enable easier access to products (Xia et al., 2023). The application of digital technologies in economic life gained additional importance due to the coronavirus pandemic (Zhang et al., 2022). The growing importance of digital technologies in everyday business activities has created the need for efficient monitoring of the effects and outcomes of the digitization process on economic activity. In these circumstances, the development of analytical tools for researching the contribution of digital technologies to economic activity arouses an increasing interest of researchers (Wang & Shi, 2021; Stanković et al., 2021; Luo & Zhou, 2022; Li et al., 2022). Along with the development of the methodological framework, there is a continuous need to establish and upgrade internationally comparable statistical data (Ferracane & van der Marel, 2020; Cahyadi & Magda, 2021; Skare et al., 2023).

This study aims to determine, explore, and critically evaluate methodological and empirical research on digital economy indices. The following research questions are addressed: What are the most cited papers on digital economy indices? What are the most cited journals in which papers on the topic have been published? What are the most important digital economy indices applied in recent research? How was the methodology based on the construction, upgrading, and application of digital economy indices chronologically improved? What are the most relevant findings from the application of digital economy indices in empirical research? What are potential future research directions for improving the measurement framework based on digital economy indices?

The research was conducted by applying a systematic literature review methodology (Tranfield et al., 2003; Prasad et al., 2018; Grilli et al., 2019; Snyder, 2019; Anton & Nucu, 2020; Buturac, 2022). The research period was from 2000 to 2022.

A systematic overview of the empirical literature on digital economy indices has not previously been conducted. This study provides important contributions to the scientific literature. First, it gives a complete picture of the published studies on digital economy indices and includes a comprehensive citation-based content analysis covering the methodological development, empirical findings, and research agenda. Second, the study brings together information on the relevant sources of published papers on digital economy indices as well as guidelines for researchers interested in applying a systematic literature review as a research method. Third, an overview of the limits and advantages of digital economy indices not only facilitates the selection and application of the appropriate index in future analytical works, but also contributes to a better interpretation of the results obtained. Finally, this contribution to the literature is motivated by the importance of further methodological development of digital economy indices in scientific research. Measuring the digital economy is not only of an economic nature, but also has statistical and mathematical implications. Therefore, the results presented here are a good basis for further research across a range of research areas.

A discussion of the methodology follows this introductory section. A citation-based analysis is conducted in Section 3. Section 4 is devoted to content analysis and includes an overview of digital economy indices, methodology development, empirical findings, and research agenda. Section 5 concludes.

2. Methodology

As research methodology, a systematic literature review is used (Tranfield et al., 2003; Prasad et al., 2018; Buturac, 2022). A more detailed explanation of the applied methodological framework, including phases, aims, and guideline questions, is presented in Table 1. In this article, the analysed research sample comprises the literature on digital economy indices published between 2000 and 2022, indexed in the ISI Web of Science database.

Table 1. Systematic Literature Review – Phases and Guideline Questions

| Phase | Aim/s | Guideline questions |
|---------------------------------------|---|---|
| Phase 1: <i>Designing the review</i> | Research questions identified. Overall review approach considered. Research strategy established. | <ul style="list-style-type: none"> • Is the literature review on digital economy indices needed? • What is the scientific contribution of the research? • What is the research scope? • What are key research questions? • What is the research strategy? |
| Phase 2: <i>Conducting the review</i> | Papers selected, classified, and explained. | <ul style="list-style-type: none"> • Is the research strategy relevant to provide a representative sample of papers on digital economy indices? • How are the criteria applied for the selection of scientific papers explained? • How is the robustness of the research methodology appraised? |
| Phase 3: <i>Analysis</i> | Content analysis of selected research papers performed. | <ul style="list-style-type: none"> • Is the research method relevant for the content analysis? • Are the data abstracted in the form of descriptive information, such as authors, years published, topic, or type of study, or in the form of effects and findings? • How are the selected research papers categorised under different themes? |
| Phase 4: <i>Writing the review</i> | Literature review reported and structured. | <ul style="list-style-type: none"> • Is the process of designing the review described transparently? • Is the literature identified, analysed, synthesised, and presented in a scientifically justified and consistent way? • Are the contributions to the academic literature realised and clearly presented? |

Source: Author's systematization following Anton and Nucu (2020), Snyder (2019), Prasad et al. (2018), and Buturac (2022).

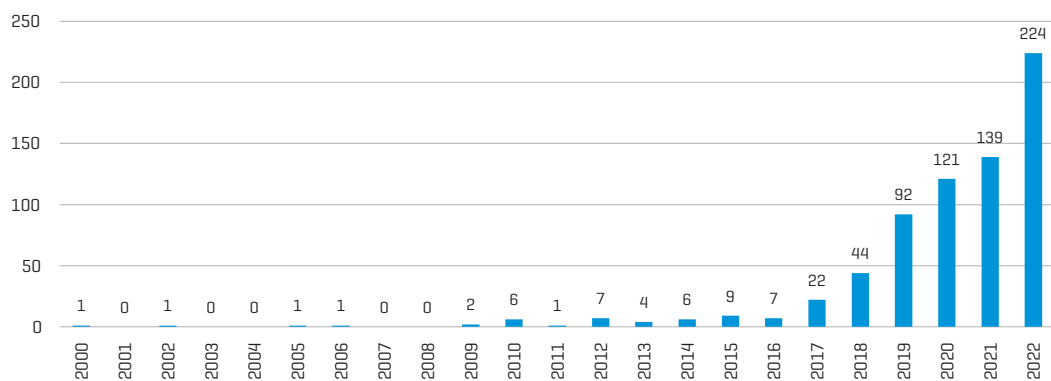
The initial studies collected according to the research aim must be sorted at the beginning of the research process. For this purpose, it is necessary to define the criteria for including articles in the research sample. The inclusion criteria for the systematic literature review in this study address the following key aspects: methodological development, geographical dimension, sectoral dimension, and empirical findings (Table 2).

Table 2. Inclusion Criteria for the Systematic Literature Review

| Inclusion criteria | Description |
|----------------------------|---|
| Methodological development | Comprise all studies that contribute to methodological development on the research topic. |
| Geographical dimension | Comprise all studies that provide new evidence on methodological development and application of digital economy indices in specific geographical regions or countries. |
| Sectoral dimension | Comprise all studies that contribute to methodological development of digital economy indices for a specific sector, such as public administration, rural sector, or finance. |
| Empirical findings | Comprise all studies that contribute to the application of empirical research of digital economy indices analysed. |

Source: Author's systematization.

The number of publications per year on digital economy indices in the 2000–2022 period is presented in Figure 1. The search for papers took place in March 2023. Until 2016, with few oscillations, a relatively small number of articles was published. But, from 2016 to 2022, the number of published articles experienced a rapid expansion.

Figure 1. Results of ISI Web of Science Search for ‘Digital Economy Indices’ in the Title of Publications for the Period 2000–2022 (Number of Publications)

Source: Web of Science database.

Other studies propose beginning the review process by searching for studies on digital economy indices (Huang et al., 2016; Anton & Nucu, 2020; Abideen et al., 2021). For this purpose, I used the ISI Web of Science, an international bibliographic database that contains highly rated journals. Article collection was based on a keyword search for the phrase ‘digital economy indices’. The preliminary search yielded an initial pool of 688 unique contributions, including peer-reviewed articles, conference proceedings, review articles, book chapters, editorial materials, and early access articles. An overview of the initial search results by document type is set out in Table 3.

Table 3. Breakdown by Document Type of Initial Contributions to the Literature on Digital Economy Indices for the Period 2000–2022

| Document type | Number of research works | % of the total |
|--------------------|--------------------------|----------------|
| Article | 526 | 76.5 |
| Proceeding paper | 108 | 15.7 |
| Review article | 9 | 1.3 |
| Book chapter | 20 | 2.9 |
| Editorial material | 3 | 0.4 |
| Early access | 20 | 2.9 |
| Data paper | 1 | 0.1 |
| Retraction | 1 | 0.1 |
| Total | 688 | 100.0 |

Source: ISI Web of Science database.

After collection, the articles were sorted in line with the paper's aim and defined methodological framework. Certain document types were eliminated in the selection process, including editorial materials and early access articles. In the next step, articles not in line with the key research questions were excluded. After collecting, sorting, and selecting the articles, the final sample comprised 170 impactful studies.

3. Citation-Based Analysis

At the very beginning of the citation-based analysis, the following research question is addressed: ‘What are the journals that have published the greatest number of articles from said research?’ The top 10 Web of Science publications, according to the number of papers published on digital economy indices, are as follows: *Sustainability*, *Advances in Economics, Business and Management Research*, *International Journal of Environmental Research and Public Health*, *Environmental Science and Pollution Research*, *Technological Forecasting and Social Change*, *Advances in Intelligent Systems and Computing*, *Computational Intelligence and Neuroscience*, *Plos One*, *Technology in Society*, and *Ekonomika Regiona – Economy of Regions*. Table 4 sets out the publications that have published more than five papers on the topic in descending order by the number of articles published, together with an average number of citations, over the 2000–2022 period. Apart from the 25 journals listed in Table 4, nine journals have published four articles on digital economy indices, 24 journals have published three articles, 55 journals have published two articles, and 82 journals have published only one article. These journals are not included to preserve space.

The results presented in Table 4 reveal a high degree of dispersion across publications of articles on the topic. Although the number of papers published on digital economy indices is relatively high, the number of papers per journal is relatively low. Similar findings are confirmed in other research fields, such as working capital management (Prasad et al., 2018), enterprise risk management (Anton & Nucu, 2020), and measures of economic forecast accuracy (Buturac, 2022). An analysis of the average number of citations per year from the Web of Science Core Collection shows that the journal *Sustainability* has the highest citations per article (58), followed by *Environmental Science and Pollution Research* (46.67).

It seems particularly interesting to analyse the most cited articles in this research area. Table 5 presents the top 20 studies on digital economy indices in descending order of citation. In addition to the titles of the articles and the number of citations, Table 5 lists the authors’ names, the year of publication, and the journal in which each article is published. The results presented in the table show that in the Web of Science Core Collection, the *Journal of Information Technology* has the highest citations per paper in the 2000–2022 period (115 citations) for the study ‘Measuring the digital divide: A framework for the analysis of cross-country differences’ (Corrocher & Ordanini, 2002). Constructing a synthetic index of digitalization, this study proposes a new model for measuring the digital divide within a set of countries or geographical areas.

The highest average number of citations per year is attributed to the *Journal of Business Research* (29 citations) for the article ‘Digital economy: An innovation driver for total factor productivity’ (Pan et al., 2022). Examining the innovation-driven effects of the digital economy on total factor productivity (TFP) in China, Pan et al. (2022) propose a new digital economy index. Analysis results confirm the hypothesis that the proposed digital economy index has a positively nonlinear relationship with total factor productivity (TFP).

Section 4 – Content Analysis – sets out the contributions of other related papers to an overview of digital economy indices, methodology development, and empirical application.

Table 4. Top 25 Source Titles (by Record Count)

| No. | Title of the journal | Number of articles | Average number of citations per year from the Web of Science Core Collection |
|------------|--|---------------------------|---|
| 1 | Sustainability | 38 | 58 |
| 2 | Advances in Economics, Business and Management Research | 13 | 1.5 |
| 3 | International Journal of Environmental Research and Public Health | 13 | 21.75 |
| 4 | Environmental Science and Pollution Research | 10 | 46.67 |
| 5 | Technological Forecasting and Social Change | 9 | 14.75 |
| 6 | Advances in Intelligent Systems and Computing | 8 | 4.67 |
| 7 | Computational Intelligence and Neuroscience | 8 | 2.5 |
| 8 | Plos One | 8 | 12.33 |
| 9 | Technology in Society | 8 | 41.33 |
| 10 | Ekonomika Regiona – Economy of Regions | 7 | 6.2 |
| 11 | Entrepreneurship and Sustainability Issues | 6 | 10.67 |
| 12 | European Proceedings of Social and Behavioural Sciences | 6 | 0.67 |
| 13 | Financial and Credit Activity: Problems of Theory and Practice | 6 | 2.67 |
| 14 | Journal of Cleaner Production | 6 | 19.29 |
| 15 | Mathematical Problems in Engineering | 6 | 1.33 |
| 16 | Proceedings of the International Conference on Business Excellence | 6 | 2.5 |
| 17 | Advances in Social Science, Education and Humanities Research | 5 | 0 |
| 18 | Economic Annals-XXI | 5 | 3.2 |
| 19 | Estudios de Economía Aplicada | 5 | 3.67 |
| 20 | Frontiers in Environmental Science | 5 | 23.5 |
| 21 | Lecture Notes in Networks and Systems | 5 | 1.75 |
| 22 | Mobile Information Systems | 5 | 0 |
| 23 | Studies in Systems, Decision and Control | 5 | 0 |
| 24 | Sustainable Development of Modern Digital Economy | 5 | 0.67 |
| 25 | Telecommunications Policy | 5 | 4.13 |

Source: Web of Science database.

Table 5. Top 20 Studies on Digital Economy Indices in Descending Order of Their Citations

| No. | Title of the paper | Author(s) | Number of citations | Average number of citations per year | Year of publication | Journal |
|-----|---|--|---------------------|--------------------------------------|---------------------|---|
| 1 | Measuring the digital divide: A framework for the analysis of cross-country differences | Corrocher, N.; Ordanini, A. | 115 | 5.23 | 2002 | Journal of Information Technology |
| 2 | Digital economy: An innovation driver for total factor productivity | Pan, W. R.; Xie, T.; Wang, Z. W.; Ma, L. S. | 87 | 29 | 2022 | Journal of Business Research |
| 3 | Digitalization in economy and innovation: The effect on social and economic processes | Afonasova, M. A.; Panfilova, E. E.; Galichkina, M. A.; Slusarczyk, B. | 70 | 14 | 2019 | Polish Journal of Management Studies |
| 4 | Digital economy development, industrial structure upgrading and green total factor productivity: Empirical evidence from China's cities | Liu, Y.; Yang, Y. L.; Li, H. H.; Zhong, K. Y. | 62 | 27.5 | 2022 | International Journal of Environmental Research and Public Health |
| 5 | Impact of ICT development on economic growth: A study of OECD European Union countries | Fernandez-Portillo, A.; Almodovar-Gonzalez, M.; Hernandez-Mogollon, R. | 56 | 14 | 2020 | Technology in Society |
| 6 | How should we understand the digital economy in Asia? Critical assessment and research agenda | Li, K.; Kim, D. J.; Lang, K. R.; Kauffman, R. J.; Naldi, M. | 53 | 13.25 | 2020 | Electronic Commerce Research and Applications |
| 7 | E-government development and the digital economy: A reciprocal relationship | Zhao, F.; Wallis, J.; Singh, M. | 49 | 5.44 | 2015 | Internet Research |
| 8 | Digital economy, technological innovation, and green economic efficiency – Empirical evidence from 277 cities in China | Li, J. L.; Chen, L. T.; Chen, Y.; He, J. W. | 49 | 16.33 | 2022 | Managerial and Decision Economics |
| 9 | Digitalization of the EU economies and people at risk of poverty or social exclusion | Kwilinski, A.; Vyshnevskyi, O.; Dzwigol, H. | 48 | 12 | 2020 | Journal of Risk and Financial Management |
| 10 | Pattern of technological innovations in small enterprises: A comparative perspective of Bangalore (India) and Northeast England (UK) | Subrahmanya, M. H. B. | 47 | 2.47 | 2005 | Technovation |
| 11 | The role of e-governance in combating COVID-19 and promoting sustainable development: A comparative study of China and Pakistan | Ullah, A.; Pinglu, C.; Ullah, S.; Abbas, H. S. M.; Khan, S. | 46 | 11.5 | 2020 | Chinese Political Science Review |
| 12 | The impact of digital technology usage on economic growth in Africa | Solomon, E. M.; van Klyton, A. | 42 | 10.5 | 2020 | Utilities Policy |

Table 5. Cont.

| | | | | | | |
|----|---|---|----|-------|------|---|
| 13 | A usability assessment of e-government websites in Sub-Saharan Africa | Verkijika, S. F.; De Wet, L. | 40 | 6.67 | 2018 | International Journal of Information Management |
| 14 | Does digital finance promote manufacturing servitization: Micro evidence from China | Chen, S. Q.; Zhang, H. | 37 | 12.33 | 2021 | International Review of Economics & Finance |
| 15 | Digitalization and society's sustainable development – Measures and implications | Jovanovic, M.; Dlacic, J.; Okanovic, M. | 30 | 5 | 2018 | Zbornik radova Ekonomskog fakulteta u Rijeci – Proceedings of Rijeka Faculty of Economics |
| 16 | The analysis of the Digital Economy and Society Index in the EU | Stavytskyy, A.; Kharlamova, G.; Stoica, E. A. | 29 | 5.8 | 2019 | Baltic Journal of European Studies |
| 17 | An alternative measure of the ICT-Opportunity Index | Emrouznejad, A.; Cabanda, E.; Gholami, R. | 27 | 1.93 | 2010 | Information & Management |
| 18 | The level of development of the digital economy in Poland and selected European countries: A comparative analysis | Moroz, M. | 25 | 3.57 | 2017 | Foundations of Management |
| 19 | Digital financial inclusion and sustainable growth of small and micro enterprises – Evidence based on China's New Third Board Market listed companies | Yang, L.; Zhang, Y. | 21 | 5.25 | 2020 | Sustainability |
| 20 | What the overall Digital Economy and Society Index reveals: A statistical analysis of the DESI EU28 dimensions | Banhidi, Z.; Dobos, I.; Nemeslaki, A. | 17 | 4.25 | 2020 | Regional Statistics |

Source: Web of Science database.

4. Content Analysis

The content analysis is divided into four main sections: an overview of digital economy indices, a review of methodology development, an overview of empirical findings, and a research agenda. The chapter begins with an overview of digital economy indices, including a description of the main features of each index.

4.1. An Overview of Digital Economy Indices

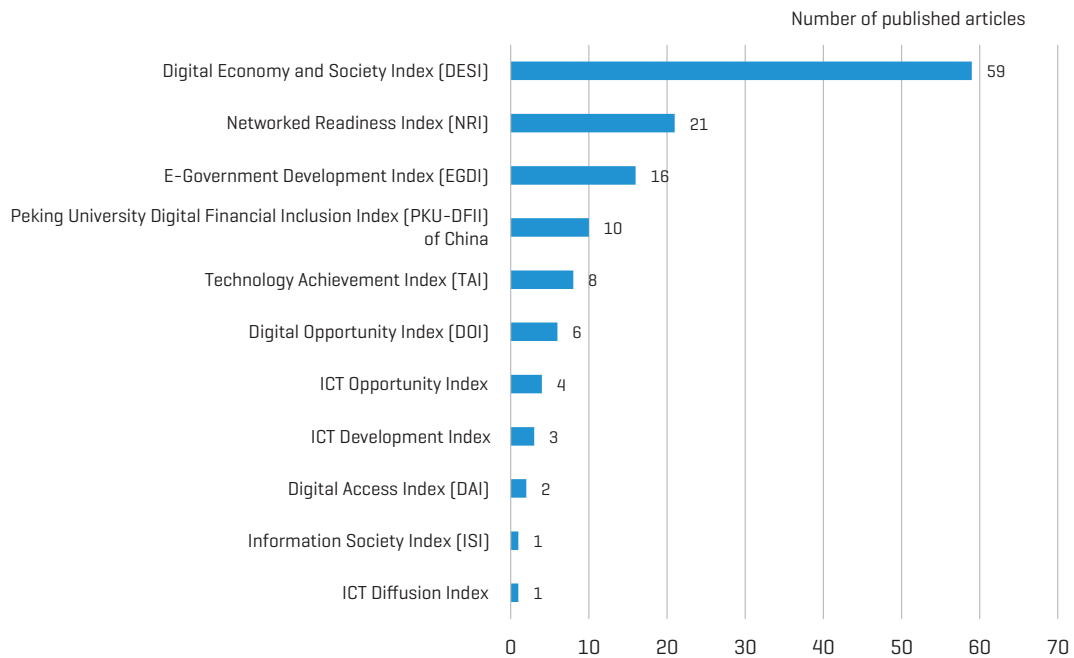
Digitalization leads to significant changes not only in people's everyday lives but also in all spheres of economic life. The direction and dynamics of these changes certainly differ between individual countries. All these changes require an appropriate analytical framework for conducting scientifically justified and consistent research. This includes an analysis of the dynamics of the progress of the digital economy in individual countries, the causes and consequences of the emergence of various trends, and the effects of the digital economy on the development of individual economic sectors. In developing the methodological framework, digital economy indices certainly play an unavoidable role. In the last 20 years, various institutions have contributed to the creation and development of digital economy indices, such as the United Nations (UN), World Economic Forum (WEF), International Telecommunication Union (ITU), and Economist Intelligence Unit (EIU). Among all these institutions, the International Telecommunication Union (ITU) stands out from the rest. Namely, this institution alone has created four digital economy indices: the Digital Access Index (2003), the Digital Opportunity Index (2005), the ICT Opportunity Index (2009), and the ICT Development Index (2009). Considering the sample size of countries included in the application of the index and its wide usage in scientific and professional research, the NRI index, developed in 2002 by the World Economic Forum (WEF), plays a very important role. Among the scientific community, a special place in the development of digital economy indices is occupied by the Institute of Digital Finance at Peking University, which designed the Digital Financial Inclusion Index (PKU-DFII). To monitor the digital development of the European Union countries, the European Commission created the DESI index in 2014 (European Commission, 2022).

Desai et al. (2002) recognized the necessity of designing an index that calculates a country's skills with respect to the latest technologies, such as work skills, innovation skills, etc. Thus, in 2002, the Technology Achievement Index (TAI) was constructed and developed. The digitization of public services is extremely important for successful economic development, as well as overall social development. Therefore, in 2002, the United Nations developed the E-Government Development Index (EGDI). The EGDI index assesses the government's online presence in terms of service delivery, telecommunication infrastructure, and human resource endowment. It is calculated for the 193 member states of the UN. EGDI can serve as a benchmarking tool for countries to identify their strengths and weaknesses and shape their e-government policies. In addition to various institutions, numerous researchers have recently made a significant contribution to the methodological development of digital economy indices (Wong et al., 2009; Gaaloul & Khalfallah, 2014; Ojanperae et al., 2019; Ferracane & van der Marel, 2020; Popov & Semyachkov, 2020; Goh, 2021; Li et al., 2021; Corrocher & Ordanini, 2002; Bai et al., 2022; Luo & Zhou, 2022; Wang et al., 2022; Chen & Wu, 2022; Toh Hao

et al., 2022). This will be discussed in more detail in section 4.2. A detailed overview of digital economy indices, including the publisher, year of first publication, number of countries for which the index is calculated, a short description of each index, and a list of selected papers in which the respective indices are applied is set out in Table 6.

Considering the broad spectrum of stakeholders interested in creating and applying digital economy indices, it is not surprising that individual digital economy indices have different roles and levels of importance in scientific research. Figure 2 sets out the distribution of digital economy indices by the number of published scientific articles in which the indices are applied. It can be noticed that the DESI index is the most represented and applied in scientific research, followed by the NRI index and the EGDI index.

Figure 2. Distribution of Digital Economy Indices by the Number of Published Articles



Source: Web of Science database.

Also, some indices were not primarily created for scientific purposes and, therefore, are rarely used in scientific papers, such as the Information Society Index (ISI), the Digital Access Index (DAI), and the ICT Development Index. A comparative analysis of the structure of e-indices and an assessment of their coherence were made in Kononova's study (2015). Considering the comprehensiveness of the information contained in each individual index, Kononova (2015) especially emphasizes the importance of the availability and reliability of the data used to calculate the individual index. Considering the representation and significance of the presented indices in scientific research (Figure 2), in the next sections of this study, the focus will be on the following indices: Digital Economy and Society Index (DESI), Networked Readiness Index (NRI), E-Government Development Index (EGDI), Peking University Digital Financial Inclusion Index (PKU-DFII), Technology Achievement Index (TAI), and Digital Opportunity Index (DOI).

Table 6. An Overview of Digital Economy Indices

| Index | Publisher | First publication | Countries covered | Short description | Selected papers |
|--|---|-------------------|-------------------|--|---|
| Digital Economy and Society Index (DESI) | European Commission | 2014 | 27 | DESI is an index that summarises indicators of Europe's digital performance and tracks the progress of EU countries. On an annual basis, it monitors the performance of member states in digital connectivity, digital skills, online activity, and digital public services. | Liu (2022); Laitso et al. (2020); López Peláez et al. (2020); Stavytsky et al. (2019); Elmassah and Hassanein (2022); Li et al. (2020); Borowiecki et al. (2021); Banihidi and Dobos (2023); Olczyk and Kuc-Czarnecka (2022); Kovács et al. (2022); Volkova et al. (2021); Ershova et al. (2021); Esses et al. (2021) |
| Digital Access Index (DAI) | International Telecommunication Union (ITU) | 2003 | 181 | DAI is an index that measures the overall ability of individuals in a country to access and use new ICTs. It is based on four fundamental variables: infrastructure, affordability, knowledge and quality, and actual usage of ICTs. | Nauriyal and Bhalla (2006); Kononova (2015) |
| Digital Opportunity Index (DOI) | International Telecommunication Union (ITU) | 2005 | 181 | The DOI index is a standard analytical tool for measuring the digital divide and comparing ICT performance within and across countries. This index summarises 11 ICT indicators grouped into three clusters: opportunity, infrastructure, and utilization. | James (2007); Kelly and Biggs (2007); Haider et al. (2021); Hanafizadeh et al. (2009); James (2008) |
| E-Government Development Index (EGDI) | United Nations | 2002 | 193 | The EGDI index is used for the analysis of e-government development of UN member states. It includes three variables: provision of online services, telecommunication connectivity, and human capacities. | Yarovoy et al. (2020); Zhao et al. (2022); Bilal (2017); Anisenco et al. (2017); Osman and Zabliith (2021); Ullah et al. (2021); Yerina et al. (2021); Surjit and Das (2020); Vysochyna et al. (2021); Whitmore (2012) |
| ICT Development Index | International Telecommunication Union (ITU) | 2009 | 154 | The IDI index was used for the analysis of the developments in information and communication technology (ICT) among countries. It included 11 indicators and was published from 2009 to 2017. | Sukhodolov and Popkova (2018); Zanizdra et al. (2021); Alibekova et al. (2020); Lomakina et al. (2021) |
| ICT Diffusion Index | United Nations Conference on Trade and Development (UNCTAD) | 2003 | 180 | The ICT Diffusion Index was used for the analysis of ICT diffusion across countries. It included 8 indicators grouped into two clusters: connectivity and access. This index was later abandoned in favour of the ICT Opportunity Index. | Kononova (2015), Kallal et al. (2021) |

Table 6. Cont.

| | | | | | |
|---|---|------|-----|--|--|
| ICT Opportunity Index (ICT-OI) | International Telecommunication Union (ITU) | 2009 | 183 | Besides the DOI index, the ICT-OI index is a useful analytical tool. The DOI index is based on three clusters: opportunity, infrastructure, and utilization, and uses the arithmetic average score measurement, whereas the ICT-OI index is measured using a geometric mean and focuses more on conventional ICT. | Emrouznejad et al. (2010); Atici (2010); Szabó and Chiriac (2016) |
| Information Society Index (ISI) | International Data Corporation (IDC) | 1997 | 53 | The ISI index measures the country's ability to access and absorb information and information technology. It summarises 15 variables arranged into four subindices. | Kononova (2015) |
| Networked Readiness Index (NRI) | World Economic Forum | 2002 | 131 | NRI is an index that is used for the analysis of the degree of readiness of countries to exploit opportunities offered by information and communications technology. It includes 58 indicators distributed in four dimensions: technology, people, governance, and impact. | Kirkman et al. (2002); Petrenko et al. (2017); Spivakovskyy et al. (2021); Wu et al. (2012); Moroz (2017); Samoilenko and Osei-Bryson (2019); Yera et al. (2020); Zelenkov and Lashkevich (2020); Petkova et al. (2019); Topornin et al. (2021); Vysochyna et al. (2021) |
| Peking University Digital Financial Inclusion Index (PKU-DFII) of China | Institute of Digital Finance at Peking University | 2011 | 1 | PKU-DFII is an index that is used for the analysis of digital finance in China. This index represents a sort of upgrade of the financial inclusion index proposed by the World Bank. It includes three variables: breadth of coverage, depth of usage, and level of digitization. | Guo et al. (2020); Yang and Zhang (2020); Chen and Zhang (2021); Wang (2022); Huiyuan and Xiaomin (2021); Rao et al. (2022); Xin et al. (2022); Zhao and Feng (2022) |
| Technology Achievement Index (TAI) | Desai et al. (2002) | 2002 | 167 | TAI is an index that calculates the country's skills concerning the latest technologies, such as work skills, innovation skills, etc. It was originally developed by Desai et al. (2002). The first version of the index was well-known as TAI-02. Following TAI-02, TAI-09 and TAI-15 were proposed. While TAI-02 analysed 72 countries, TAI-09 investigated 91 countries, and TAI-15 analysed 167 countries (Incekara et al., 2017). | Desai et al. (2002); Cherchye et al. (2008); Nasir et al. (2009); Márquez-Ramos and Martínez-Zarzoso (2010); Burinskienė and Pipirienė (2014); Ali et al. (2015); Incekara et al. (2017) |

Source: Author's systematization.

4.2. Methodology Development

Section 4.2, Methodology Development, begins with detailed insight into existing measurement approaches and later continues with an overview of the latest research and scientific contributions in the field of digital economy indices development.

4.2.1. Existing Measurement Approaches

The methodological tools for analysing the digital economy have evolved with information and communication technology (ICT). Considering the wide range of users interested in the results of the development of the digital economy, the development of the methodology for monitoring the digital economy is a matter of interest not only for the scientific community but also for other stakeholders in society (the business sector, financial institutions, the telecommunications sector, technology parks, investors, etc.). This additionally emphasizes the importance of developing an appropriate methodological framework, such as the digital economy indices. Several indices of the digital economy have been profiled in scientific research in the last 20 years. They have found their application primarily as a methodological basis in conducting empirical research (Vidruska, 2016; Aniscenko et al., 2017; Incekara et al., 2017; Jurcevic et al., 2020; Liu, 2022; Olczyk & Kuc-Czarnecka, 2022; Ogrea & Herciu, 2022).

At the same time, some indices have disappeared and are no longer calculated, while some new indices of the digital economy have appeared. Also, there are indices of the digital economy that changed their name as they improved. Improving the methodology in terms of the construction, calculation, and interpretation of individual indices of the digital economy induces the increasing interest of researchers. Today's role and significance of the digital economy require continuous methodological improvements. Thereby, researchers are endeavouring to remove the existing methodological limitations of individual indices (Archibugi & Coco, 2004; Fathey & Othman, 2013; Rath, 2016; Jovanović Milenkovic et al., 2016; Ojanperä et al., 2019; Stanković et al., 2021; Olczyk & Kuc-Czarnecka, 2022).

Of the digital economy indices analysed, the DESI, NRI, and EGDI indices are the most used in scientific research today (Figure 2). In addition to the mentioned indices, the DOI, TAI, and PKU-DFII indices have also played a more significant role in scientific research in the last 20 years. A more detailed description of the basic methodological features of the selected digital economy indices, including main dimensions, total indicator count, and range of indices, is set out in Table 7.

Also, it seems particularly important and useful to analyse the advantages and limits of a particular index of the digital economy (Table 8).

Table 7. Basic Methodological Features of the Selected Digital Economy Indices

| | | | |
|--------------------------------|--|---|--|
| Index name | Network Readiness Index | Digital Economy and Society Index | E-Government Development Index |
| Abbreviation | NRI | DESI | EGDI |
| Main dimensions | Environment (25%), readiness (25%), usage (25%), impact (25%) | Connectivity (25%), human capital (25%), use of the internet (15%), integration of digital technology (20%), digital public services (15%) | Provision of online services (33%), telecommunication connectivity (33%), human capacity (33%) |
| Total indicator count | 54 | 30 | 3 |
| Countries included | Worldwide, 143 (NRI 2015) | EU-28 countries (DESI 2016) and candidates | All 193 United Nations member states |
| Maintained by | World Economic Forum | European Commission | United Nations |
| Possible range of index | 0–100 | 0–1 | 0–1 |
| Period available | 2003–2022 | 2013–2022 | 2003–2022 |
| | | | |
| Index name | Peking University Digital Financial Inclusion Index | Technology Achievement Index | Digital Opportunity Index |
| Abbreviation | PKU-DFII | TAI | DOI |
| Main dimensions | Breadth of coverage (54.0%), depth of usage (29.7%), level of digitalization (16.3%) | Technology creation (25%), diffusion of recent innovations (25%), diffusion of old innovations (25%), human skills (25%) | Opportunity (33%), infrastructure (33%), utilization (33%) |
| Total indicator count | 33 | 8 | 11 |
| Countries included | The People's Republic of China | Worldwide, 179 (TAI-20) | Worldwide, 181 countries |
| Maintained by | Institute of Digital Finance at Peking University | United Nations Development Programme (UNDP) | International Telecommunication Union (ITU) |
| Possible range of index | It captures information on various aspects of financial inclusion, where 0 represents complete financial exclusion. The minimum index value is 0. The higher the index value, the higher the level of digital financial inclusion. | The countries included in the TAI index are divided into four sub-groups called leaders (TAI > 0.5), potential leaders (TAI = 0.35–0.49), dynamic adopters (TAI = 0.20–0.34), and marginalized (TAI < 0.20) (Desai et al., 2002). | The Digital Opportunity Index aims to measure the ease of access that citizens have to information and communication technologies (ICT), in terms of both availability and price, on a scale that ranges from zero, representing a total lack of ICT access, to one, representing full ICT access. |
| Period available | 2011–2018 | 2000–2018 | 2004–2006 |

Source: Author's systematization.

Table 8. Advantages and Limits of Alternative Digital Economy Indices

| Index | Advantages | Limits |
|--|--|--|
| Digital Economy and Society Index (DESI) | <p>The DESI index is used for the analysis of Europe's overall digital performance as well as its digital competitiveness. It is a measurement system that is widely used and quoted by scholars, experts, and policymakers. The main advantage of this index is that it is measured in 28 countries and by doing so allows comparison between them. The DESI index ensures a complete picture of the digital ecosystem in the EU and member countries. A separate dataset (International Digital Economy and Society Index, I-DESI) aims to extend the results of DESI to 17 non-EU countries.</p> | <p>Since measurements are collected in 28 different countries, the methodology is determined to be general and applicable in all countries. Therefore, the results are also general and unsuitable for deep analysis and explanation of certain phenomena. The time between the data collection and publication is often very long, frequently resulting in outdated assessments. Indicators and sub-indicators change year by year, making comparing time series performances difficult because these corrections are not emphasized enough. There are also significant differences between the statistical offices and data collection methods between countries.</p> |
| Networked Readiness Index (NRI) | <p>The NRI index is a useful analytical tool for the analysis of the digital development of countries. This index is one of the most comprehensive assessments of ICT readiness and has been used by an increasing number of governments as a basis for their national ICT strategies.</p> <p>In contrast to the 28 countries covered by the Digital Economy and Society Index (DESI) of the European Union, which measures only the most developed countries, the NRI index indicates the digital development of 130 countries around the world.</p> <p>The NRI index is based on four fundamental variables: technology, people, governance, and impact. It covers issues ranging from future technologies such as artificial intelligence to the role of digital technologies in achieving the sustainable development goals.</p> | <p>The NRI index's limitations can be divided into several dimensions: missing values, reference year, normalization factor, and consistent data collection.</p> <p>Missing values: The NRI index represents relative index scores, which implies that a missing value for one country affects the index score of other countries.</p> <p>Reference year: The data underlying the NRI do not refer to a single year but several years, depending on the latest available year for any given variable. In addition, the reference years for different variables are not the same for each country due to measures to limit the number of missing data points.</p> <p>Normalization factor: Most NRI variables are normalized using GDP, population, or other factors with the intention of enabling cross-economy comparability. However, this implies that year-on-year changes in individual indicators may be driven either by the variable (numerator) or by its normalization factor (denominator).</p> <p>Consistent data collection: Analysing the change in year-on-year performance is based on consistent data collection through the years. Modifications of variables or the data collection process could produce changes in the ranking of countries that do not reflect the actual state of their digital development.</p> |
| Peking University Digital Financial Inclusion Index (PKU-DFII) of China | <p>The PKU-DFII index measures the development of digital financial inclusion in different regions in the People's Republic of China. It contains useful information for scholars, regulators, and industry insiders.</p> | <p>Due to the lack of comparable data, it is not entirely possible to get a comprehensive picture of digital financial inclusion across all of China's regions. Also, this index was constructed only for the regions of China, which excludes international comparability and significance of this index on a global level.</p> |

Table 8. Cont.

| Index | Advantages | Limits |
|--|--|---|
| E-Government Development Index (EGDI) | E-government services provide a range of benefits, such as enabling efficient, low-cost, and transparent services to citizens and the business sector through integrating and sharing knowledge and resources (Janowski, 2015; Sivarajah et al., 2015). Therefore, it is important to establish and continuously improve the analytical framework for analysing the effectiveness of e-government services. One of the most important analytical tools for the analysis of the state of e-government development progress is the EGDI index. | Despite the wide application of the EGDI index, there are numerous scholars who emphasize the limitations of the EGDI index. For example, Whitmore (2012) suggests a modification in calculating the EGDI index by using factor analysis. Kabbar and Dell (2013) suggest the inclusion of the gross domestic product (GDP) variable in the calculation of the EGDI index. They argue that the adjusted EGDGDP provides a better assessment of a countries' e-government development as it measures the country's performance relative to what would be expected of that country in terms of GDP rather than the absolute measure currently given to each country. |
| Technology Achievement Index (TAI) | The TAI index implements two standardized indicators to assess the extent of innovation in the nation. One of these indicators is the exact number of patents granted per capita, which informs economists about the current status of actions. The other is royalty receipts, which are accompanied by license charges from foreign countries per capita. This is an effective statistic that helps us assess the relevance of qualified past innovations. The TAI index provides insightful knowledge on the frequency and pattern at which innovative practices, theories, or manufactured items gain popularity among a certain community. | The TAI index is primarily oriented on outputs rather than inputs such as numbers of scientists, R&D expenditures, or policy environments. In the calculation of the TAI index, all indicators in a particular dimension have equal weight. Also, the dimensions have equal weight in the final index (one quarter). This means higher performance in one area can compensate for weakness in another, improving the overall ranking and making a country rank among a different class of countries than where it actually belongs. |
| Digital Opportunity Index (DOI) | The DOI index is widely used. It is calculated for 181 countries of the world. This includes both poor and rich countries. Eleven indicators are included in the calculation of the DOI index. Because of its wide application, simplicity, and availability, the DOI index has become a standard analytical tool that researchers, governments, operators, and others use to analyse the digital divide and ICT performance between countries. | Limitations of the DOI index include a lack of data for the analysis of ICT infrastructure and access, and the use of equal weighting or experts' opinions to aggregate the indicators. Another issue is insufficient methodological harmonization between countries, which is manifested in the method of data collection, classification, and processing. This ultimately reduces and limits the quality of interpretation of the obtained index values for individual countries. |

Source: Author's systematization.

In this regard, some common features for all indices can be extracted based on the presentation of the advantages and limitations of individual indices of the digital economy. The contribution of digital economy indices in scientific research stems from identifying the new trends in digitalization of the economy, the causes of positive changes in digital development, as well as differences in the degree of digitization of individual countries. In addition, they are often easily interpreted. The advantages of using digital economy indices are often closely related to their disadvantages. One of the main limitations of these indices is the oversimplification of complex interrelations, i.e., they reduce the digital development to a single value, which in some cases could lead to wrong conclusions (Vehovar et al., 2006). Furthermore, a continuous problem of the digital economy indices is related to the variables involved in designing and calculating the individual indices (Cruz Jesus et al., 2012). The problem of including certain variables in the index stems from the fact that accelerated technological development brings the need to include new variables in the index and exclude some existing ones. Related to that issue, the always present limitation is how to determine the weight of individual variables included in calculating the index. Ultimately, the weight of an individual variable can significantly determine the final value of the composite index and influence the interpretation of the results obtained.

The aforementioned limitations have motivated numerous researchers to improve the existing methodological framework and the digital economy indices (Wong et al., 2009; Gaaloul & Khalfallah, 2014; Corrocher & Ordanini, 2002).

Wong et al. (2009) emphasized the disadvantage of the digital economy indices in terms of the exclusion of certain social groups from the information society (such as the elderly and those on a low income). Therefore, these authors proposed a new digital index to analyse the degree of inclusion of different disadvantaged groups in an information society.

Gaaloul and Khalfallah (2014) highlighted the dependence of the values of digital economy indices on the weighing scheme used to aggregate individual indicators or sub-indicators, which can affect the credibility of the index. They proposed revaluating the Digital Access Index by applying the data envelopment analysis approach to overcome these limits. Bedford (2013) developed a new knowledge economy index based on a more holistic and balanced view of a knowledge society.

Corrocher and Ordanini (2002) emphasized the limitations of the methodological framework in the analysis of the digital divide. Therefore, these authors created a new methodology for measuring the digital divide within a set of countries or geographical areas. A new synthetic index of digitalization was developed that includes the factors of digitalization as follows: communication infrastructure, human resources, competitiveness of the information and communication providers, degree of competition among different operators, market diffusion, and size of the digital market. The new synthetic digitization index made it possible to assess the digital divide between different countries and geographical areas.

In addition to Corrocher and Ordanini (2002), other authors have contributed to the development of the methodological framework in the field of the digital divide (Cruz Jesus et al., 2012; Park et al., 2015). Cruz Jesus et al. (2012) analysed the digital divide across the European Union. Using principal components analysis, they constructed an original index of digitalization. Exploring the digital divide in a sample of 108 countries, Park et al. (2015)

created a new ICT development index. The methodological framework was based on applying the method of principal components and including conventional ICT development indicators.

4.2.2. Ongoing Research

Recently, the development of digital economy indices has been the subject of interest of numerous researchers (Chen & Wu, 2022; Luo & Zhou, 2022; Li et al., 2021; Wang et al., 2022; Bai et al., 2022; Wang et al., 2022; Popov & Semyachkov, 2020; Wang et al., 2022; Ojanperae et al., 2019; Toh Hao et al., 2022; Ferracane & van der Marel, 2020; Goh, 2021). Applying data on provinces in China for the period from 2012 to 2018, Chen and Wu (2022) constructed a new index for the analysis of China's provincial digital economy. The index consists of six dimensions: digital infrastructure construction level, digitalization level of the society advanced by ICT, digital technology innovation capability, economic growth promoted by ICT, development level of emerging digital economy industries, and capitalization level of digital economy enterprises. To create the weights for these dimensions, Chen and Wu (2022) applied the CRITIC methodology (Yalçın & Ünlü, 2018). The following equation gives the weights:

$$W_i = \frac{C_i}{\sum_j^n C_i} \quad i = 1, 2, \dots, n$$

$$C_i = \delta_i \sum_j^n (1 - R_{ij}) \quad i = 1, 2, \dots, n, \quad i \neq j$$

where δ_i denotes the standard deviation of indicator i and R_{ij} denotes the correlation coefficient between indicator i and indicator j .

Luo and Zhou (2022) emphasize the lack of a unified evaluation index system for the digital economy. Therefore, they developed a digital economy evaluation index, which consists of four dimensions: digital infrastructure, digital industry scale, innovation capability, and digital inclusive finance. Each of these dimensions includes appropriate digital indices such as the number of broadband internet users per 10,000 people, the number of mobile phone users per 10,000 people, per capita telecom business volume (Yuan), the number of patents in key industries of the digital economy, etc. The proposed index was tested on a sample of 31 Chinese provinces from 2011 to 2020. After Luo and Zhou (2022) defined the dimensions and appropriate indices, they eliminated the influence of dimensionality using the range standardization method. In the next step, the entropy weight method was used to calculate the weight of each index. Finally, the authors used the weighting method to explore the development of the digital economy in China's provinces. The equations are as follows:

$$A_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}$$

$$P_{ij} = \frac{A_{ij}}{\sum_{i=1}^n A_{ij}}$$

$$e_j = - \left(\frac{1}{\ln(n)} \right) \sum_{i=1}^n P_{ij} \ln(P_{ij})$$

$$\omega_j = \frac{1 - e_j}{\sum_{j=1}^m (1 - e_j)}$$

$$F = \sum_{j=1}^m \omega_j \times A_{ij}$$

where X_{ij} denotes the original values, and A_{ij} denotes the normalized values. P_{ij} represents the proportion of the i th province in the j th index. At the same time, e_j denotes the information entropy, ω_j is the weight of the j th index, and F denotes the digital economy development level.

To overcome the methodological gap in the analysis of the effects of the digital economy on environmental quality, Li et al. (2021) constructed a comprehensive development index of the digital economy and environment. Their contribution to methodology development is extremely important due to the increasing interest of researchers to contribute to science with empirical studies on the topic of digital economy and environment. In developing a comprehensive index, Li et al. (2021) first proposed the key elements of the index structure (dimensions, indices). They divided the digital economy into three dimensions: digital infrastructure, digital talent, and digital industry value. The dimensions of environmental quality are as follows: ecological environment, resource consumption, and environmental conservation. Besides the three dimensions, the authors proposed nine indices for the digital economy and 13 indices for environmental quality. As in the study of Luo and Zhou (2022), Li et al. (2021) used the entropy weight method to obtain the weight of each indicator. The construction procedure of the comprehensive development level index of the digital economy and environment is divided into several steps:

- Normalize the index data to obtain the normalized data u_{ij}^n
 Positive index: $u_{ij}^n = \left[\frac{u_{ij} - \min u_{ij}}{\max u_{ij} - \min u_{ij}} \right] \times 0.9 + 0.1; \quad 1 \leq i \leq n$
 Negative index: $u_{ij}^n = \left[\frac{\max u_{ij} - u_{ij}}{\max u_{ij} - \min u_{ij}} \right] \times 0.9 + 0.1; \quad 1 \leq i \leq n;$
- Calculate the proportion of indices: $p_{ij} = \frac{u_{ij}^n}{\sum_{i=1}^n u_{ij}^n};$
- Calculate the entropy value of index j : $e_j = - \left(\frac{1}{\ln(n)} \right) \sum_{i=1}^n p_{ij} \ln(p_{ij});$
- Calculate the difference coefficient of the j index and obtain the weight;
- Calculate the coefficient of difference: $\omega_j = \frac{1 - e_j}{\sum_{j=1}^m (1 - e_j)};$
- $U_i = \sum_{j=1}^m \lambda_{ij} u_{ij}^n$ represents the function of two subsystems (digital economy and environmental quality) composed of three dimensions in each subsystem. In addition, there are 22 indices in total, distributed in a way that 9 indices are included in the digital economy, and 13 indices are included in environmental quality. The weight of an individual index is denoted as λ_{ij} .

Based on the existing n -dimensional system interaction coupling model:

$$C_n = n \times \sqrt[n]{\frac{U_1 U_2 \dots U_n}{(U_1 + U_2 + \dots + U_n)^n}}$$

the authors derived the two-dimensional coupling function for the digital economy and environmental quality:

$$C_2 = 2 \times \sqrt{\frac{U_1 U_2}{(U_1 + U_2)^2}}$$

The study by Li et al. (2021) takes $n = 2$, C denotes the coupling degree between the digital economy and environmental quality, and its value is between 0 and 1.

When C tends to 0, the coupling system composed of the digital economy and environment is in a coupling-detuned state. When C tends to 1, the coupling system composed of the digital economy and environment is in a high-quality coupling state. The degree of coupling can effectively reflect the strength of action between the digital economy and the environment, but this function also has shortcomings. It cannot fully reflect the overall function and comprehensive, coordinated development level of the digital economy and the environment. It cannot match the actual economic significance between U_1 and U_2 . Therefore, this study establishes the coupling coordination degree function as follows:

$$D = \sqrt{C \times T}$$

$$T = \alpha U_1 + \beta U_2$$

where T denotes the comprehensive development level index of the digital economy and environment, C represents the degree of coupling, and α and β are undetermined coefficients.

Several other studies also contributed to the methodology development related to the digital economy and environment (Wang et al., 2022; Bai et al., 2022; Wang et al., 2022; Popov & Semyachkov, 2020; Wang et al., 2022). Wang et al. (2022) proposed a comprehensive digital economy index for the purpose of analysing the role of the digital economy in the development of a low-carbon society. The research was conducted on a sample of 30 provinces in China for the 2006–2017 period. Analysing the effects of the digital economy on environmental quality, Bai et al. (2022) concluded that the existing literature is deficient on how the digital economy affects urban environmental pollution. To fill this gap, these authors developed an urban digital economy index system. In the analysis of the role of the digital economy in green innovation, Wang et al. (2022) constructed a comprehensive digital economy index. Popov and Semyachkov (2020) proposed an index methodology for assessing the digitalization of the urban environment. Exploring the link between digitalization and carbon emissions, Wang et al. (2022) proposed a new digitalization index. In the construction of the index, they employed the entropy value method and spatial Markov chain. Analysing the implications of the digital economy on urban innovation, Huang et al. (2022) developed a digital economy index. The index construction was based on city-level data from China. Chen et al. (2022) created an evaluation index system of digital economy development. The quality of the index was estimated by using the entropy method. Ojanperae et al. (2019) proposed the development of a Digital Knowledge Economy Index based on the usage of traditional and novel data sources (GitHub).

To analyse the digital performance of Malaysia, Toh Hao et al. (2022) developed a digital economy index. Index construction was based on the sample of Malaysia in the 2000–2018 period. The proposed index consists of four dimensions: infrastructure, empowering society, innovation and technology adoption, and jobs and growth.

Ferracane and van der Marel (2020) created the Digital Platform Restrictiveness Index (DPRI)

as a measure of restrictiveness for online platforms. Considering the restrictiveness of each policy measure applied by a country, the DPRI index quantifies the trade cost position with respect to digital platform policies of an individual country. Goh (2021) proposed a new digital readiness index, which aims to assess leading arbitral institutions on their level of digital readiness. The new index consists of five indicators: case filing and management, arbitrator panel, meetings/hearings, security, and thought leadership.

4.3. Empirical Findings

Empirical research on the digital economy in the last two decades has attracted an increasing interest of researchers (Liu, 2022; Stavitsky et al., 2019; Rakicevic et al., 2019; Li et al., 2020; Cruz Jesus et al., 2012; Park et al., 2015; Borowiecki et al., 2021; Imran et al., 2022; Karnitis et al., 2019; Skare et al., 2023; Milashovska et al., 2022; Melnychenko et al., 2021; Elmassah & Hassanein, 2022; Volkova et al., 2021; Banhidi & Dobos, 2023; Noja et al., 2022; Moroz, 2017; Wang et al., 2022; Wu et al., 2023; Shen & Zhang, 2022; Han et al., 2022; Lomakina et al., 2021; Marshall et al., 2020; Alfonso & Pariso, 2021; Szabolcs et al., 2022; Wang & Shi, 2021; Huang et al., 2022; Lyu et al., 2023; Chen et al., 2022; Chen & Wu, 2022). The indices of the digital economy (EGDI, DESI, NRI, TAI, PKU-DFII, DOI), on which the methodological basis of empirical research is based, have a special role and importance. As digitization affects all economic areas, so is there a wide spectrum of empirical research in which digital economy indices find their application (Grinberga-Zalite & Hernik, 2019; Banhidi et al., 2020; Olczyk & Kuc-Czarnecka, 2022; Basol & Cumhur Yalçın, 2021; Kovács et al., 2022; Jovanović et al., 2018; Vidruska, 2019; Spivakovskyy, 2021; Jovanović et al., 2016; Wu et al., 2012; Yera et al., 2020; Yarovoy et al., 2020; Aniscenko et al., 2017; Wang, 2022; İncekara et al., 2017). A significant part of scientific research is continuously focused on digitalizing public administration (Surjit & Das, 2020; Dobrolyubova, 2021; Stofkova et al., 2022). In doing so, the degree of digitization, as well as the availability and efficiency of public services, is analysed (Todoruș, 2018; Ullah et al., 2021; Verkijika & De Wet, 2018). In analysing the success of digitization of the economy, authors often make comparisons between countries. With the construction and development of the DESI index, this has become particularly evident in the case of the European Union countries (Stavitsky et al., 2019; Borowiecki et al., 2021; Soava et al., 2022; Liu, 2022). Observing the effects of digitization on macroeconomic variables, as could be expected, the largest part of the research is devoted to the effects of digitization on economic growth (Olczyk & Kuc-Czarnecka, 2022; Fernández-Portillo et al., 2020; Ivanović-Đukić et al., 2019; Vyshnevskiy et al., 2021; Zhao et al., 2022). The construction and development of the Digital Financial Inclusion Index by Peking University facilitated the implementation of empirical research on the effects of digitalization on financial inclusion (Yang et al., 2020; Zhou et al., 2022). The largest number of these studies was conducted on a sample of Chinese provinces (Zou et al., 2021; He et al., 2022). The processes of digitization of the economy are closely linked to innovation. Therefore, the effects of the digital economy on innovation are inducing an increasing interest of researchers (Martínez et al., 2022; Pan et al., 2022; Rao et al., 2022; Xu & Li, 2022). The latest research is particularly focused on the effects of digitization on the environment (Shen et al., 2022; Guo et al., 2022). Some researchers investigate the contribution of digitization to the development of the competitiveness of the economy (Laitsou et al., 2020; Hurduzeu et al., 2022; Stanković et al., 2021).

A classification of key empirical findings is presented in Table 9.

Table 9. Classification of Empirical Findings

| Subject of research | Title of the paper | Author/s | Year of publication | Empirical findings |
|---|--|--|---------------------|--|
| Digitalization of public services | Digital technologies and the modernization of public administration | Todoruț, A. V.; Tselentis, V. | 2018 | It is proved that the rapid development of technologies enables an increasing variety and sophistication of online services. |
| | The role of e-governance in combating COVID-19 and promoting sustainable development: A comparative study of China and Pakistan | Ullah, A.; Pinglu, C.; Ullah, S.; Abbas, H. S. M.; Khan, S. | 2021 | It is confirmed that by adopting China's e-governance model, the Government of Pakistan will be able to improve public services for citizens and the business sector in terms of better coordination, standardization of services, creation of synergies, and realization of cost-effectiveness. |
| | Accessibility and usability analysis of Indian e-government websites | Surjit, P.; Daqs, S. | 2020 | A need to improve the overall accessibility and usability of India's e-government websites has been identified. |
| | A usability assessment of e-government websites in Sub-Saharan Africa | Verkijika, S. F.; De Wet, L. | 2018 | The paper evaluates 279 e-government websites from 31 Sub-Saharan African countries, and confirms that most e-government websites are poorly usable. The average usability score for the websites is 36.2%, with the most usable website having a score of only 64.8%. The usability of e-government websites is positively correlated with the EGDI index. |
| | Investigations concerning e-government adoption in transition economies | Szabó, Z. K.; Chiriac, L. | 2016 | It is confirmed that there is a very strong positive correlation between the level of e-government development and e-participation. There is a huge gap between the availability of online public services and the usage level. |
| Comparison of digital transformation in the European Union | Digital policy in European countries from the perspective of the Digital Economy and Society Index | Liu, T.-C. | 2022 | Germany, Luxembourg, and the United Kingdom confirm a high level of internet service use. Countries that are more correlated with the use of digital public services include Belgium, Sweden, Denmark, Norway, the Netherlands, Lithuania, and Malta. Countries with stronger human capital performance include Austria, Estonia, Portugal, and Spain, followed by the Czech Republic, France, and Slovenia. |
| | The analysis of the Digital Economy and Society Index in the EU | Stavytskyy, A.; Kharlamova, G.; Stoica, E. A. | 2019 | The analysis conducted on a sample of the European Union countries confirms the hypothesis that a 1% growth in the consumption index results in about a 0.2 increase in the Digital Economy and Society Index (DESI), and an increase in unemployment by 1% leads to about a 0.2 DESI decrease. |
| | Developing digital economy and society in the light of the issue of digital convergence of the markets in the European Union countries | Borowiecki, R.; Siuta-Tokarska, B.; Maron, J.; Suder, M.; Thier, A.; Zmija, K. | 2021 | It is confirmed that the EU-28 countries are undergoing a convergence process in digital development. The convergence is noticed in the following areas: connectivity, human capital, use of internet services, and digital public services. |
| | Analysis and forecast of the use of e-commerce in enterprises of the European Union states | Soava, G.; Mehedintu, A.; Sterpu, M. | 2022 | The share of companies performing e-commerce depends on the size of enterprises. A significant growth in e-commerce in most European countries is forecast in the upcoming period. |

Table 9. Cont.

| Subject of research | Title of the paper | Author/s | Year of publication | Empirical findings |
|---|--|--|---------------------|---|
| The effects of digitalization on economic growth | Digital transformation and economic growth – DESI improvement and implementation | Olczyk, M.; Kuc-Czarnecka, M. | 2022 | Connectivity has the largest impact on digital development in EU countries. Digitalization is a statistically significant variable explaining changes in GDP per capita. |
| | Impact of ICT development on economic growth | Fernández-Portillo, A.; Almodóvar-González, M.; Hernández-Mogollón, R. | 2020 | ICT drives economic growth within the framework of developed European economies. |
| | Does digitalization affect the contribution of entrepreneurship to economic growth? | Ivanović-Đukić, M.; Stevanović, T.; Rađenović, T. | 2019 | Average growth expectation entrepreneurship and new products entrepreneurship have the greatest contribution to economic growth in the EU regions with lower levels of digitization. At the same time, high growth expectation entrepreneurship and new technology development entrepreneurship have a dominant role in economic growth in the EU regions characterized by a higher degree of digitization. |
| | Economic growth in the conditions of digitalization in the EU countries | Vyshnevskiy, O.; Stashkevych, I.; Shubna, O.; Barkova, S. | 2021 | The digitalization of the economy at the present stage of technology and institution development in European Union countries does not have a decisive impact on economic growth. |
| | Dynamic influence of digital and technological advancement on sustainable economic growth in Belt and Road Initiative (BRI) countries | Zhao, S.; Zhang, Y.; Iftikhar, H.; Ullah, A.; Mao, J.; Wang, T. | 2022 | Improvements in the EGD index, high-tech exports, internet users' growth, and reductions in unemployment would increase sustainable economic growth in all Asian countries of the Belt and Road Initiative (BRI). |
| Testing of digital financial inclusion | Digital financial inclusion and sustainable growth of small and micro enterprises—Evidence based on China's New Third Board Market listed companies | Yang, L.; Zhang, Y. | 2020 | In the circumstances of high-quality development of China's economy, the improvement of digital financial inclusion and transforming of the ecological pattern of the financial industry can deliver steady financial support for the sustainable growth of small and micro enterprises and ensure the healthy development of micro enterprises. |
| | Does the level of financial cognition affect the income of rural households? Based on the moderating effect of the Digital Financial Inclusion Index | Zou, F.; Li, T.; Zhou, F. | 2021 | The advancement of the financial cognitive level stimulates the increase of rural household income. This increase has significant variations at different quantile levels of income. |
| | The impact of digital inclusive finance on provincial green development efficiency: Empirical evidence from China | He, Z.; Chen, H.; Hu, J.; Zhang, Y. | 2022 | Digital inclusive finance can significantly improve provincial green development efficiency. |
| | Will digital financial inclusion increase Chinese farmers' willingness to adopt agricultural technology? | Zhou, Z.; Zhang, Y.; Yan, Z. | 2022 | Digital financial inclusion significantly increases farmers' willingness to adopt agricultural technology. |

Table 9. Cont.

| Subject of research | Title of the paper | Author/s | Year of publication | Empirical findings |
|--|---|--|---------------------|--|
| The digital divide across countries | Club convergence and factors of digital divide across countries | Park, S. R.; Choi, D. Y.; Hong, P. | 2015 | The factors that drive a country's digitalization convergence are identified: GDP per capita, the share of service trade in GDP, the urban population ratio, and the tertiary education entrance rate. |
| | Digital divide across the European Union | Cruz Jesus, F.; Oliveira, T.; Bação, F. | 2012 | It is confirmed that there is a digital gap within the European Union. European integration processes and economic wealth contribute significantly to the digital divide. |
| Digitalization and competitiveness | Digital competitiveness in the European Union era: The Greek case | Laitsou, E.; Kargas, A.; Varoutas, D. | 2020 | The results confirm Greece's low state of digitization. The reasons for the lag lie on the demand side (businesses that consume internet services) and the offer side (institutional and governmental constraints). |
| | The interplay between digitalization and competitiveness: Evidence from European countries | Hurduzeu, G.; Lupu, I.; Lupu, R.; Ion Filip, R. | 2022 | When Western European countries are compared with Central and Eastern European countries, the export of goods is the commonest indicator that is most significantly influenced by the DESI index. Another indicator that reacts positively to digitalization for both groups of countries is skilled labour. |
| | The digital competitiveness of European countries: A multiple-criteria approach | Stanković, J. J.; Marjanović, I.; Drezgic, S.; Popovic, Z. | 2021 | The Nordic countries are confirmed as having the highest digital competitiveness. At the same time, most Eastern European countries still lag behind. |
| The effects of the digital economy on the environment | Digital economy and ecological performance: Evidence from a spatial panel data in China | Shen, X.; Zhao, H.; Yu, J.; Wan, Z.; He, T.; Liu, J. | 2022 | Although the impact of the digital economy on ecology in China has decreased over time, it has still had a significant positive effect. Also, the effect of the digital economy on ecology in China shows regional heterogeneity and is more emphasized in developed regions. |
| | Exploring the mechanism of the impact of green finance and digital economy on China's green total factor productivity | Guo, J.; Zhang, K.; Liu, K. | 2022 | The digital economy has a significant impact on green total factor productivity. The green finance and digital economy's contribution to green total factor productivity is mainly derived from technological progress. |
| The impact of the digital economy on innovation | Digitalization, innovation and environmental policies aimed at achieving sustainable production | Martínez, J. M. G.; Puertas, R.; Martín, J. M. M.; Ribeiro-Soriano, D. | 2022 | Europe has not yet been able to break the negative link between GDP and sustainability, despite the positive impact of all facets of digitalization, innovation, and environmental policies. |
| | Digital economy: An innovation driver for total factor productivity | Pan, W.; Xie, T.; Wang, Z.; Ma, L. | 2022 | The digital economy index has a positively nonlinear relationship with provincial total factor productivity in China. It is confirmed that the digital economy acts as an innovation driver for the extensive and sustainable development of total factor productivity. |
| | Digital finance and corporate green innovation: Quantity or quality? | Rao, S.; Pan, Y.; He, J.; Shangguan, X. | 2022 | The promotional impact of digital finance on corporate green innovation was confirmed in state-owned, eastern, and mature enterprises. Digital finance makes firms more transparent and funds flow more convenient. |
| | The impact of the digital economy on innovation: New evidence from panel threshold model | Xu, J.; Li, W. | 2022 | The promoting impact of the digital economy on innovation enhances with the optimization of industrial structure or the advancement of urbanization level. |

Source: Author's systematization.

4.4. Research Agenda

This section is a proposal of several scientific phases that can be carried out to improve the measurement approaches to the digital economy, i.e., digital economy indices. Based on the results presented in the previous sections, potential future research directions can be identified as follows:

- The digital level and the use of applications for communication with the state. Using survey research, Stofkova et al. (2022) confirmed that people want to be better informed about new e-government services as well as services that are planned to be launched in the future. Therefore, there is a need for research on new applications for communication with the state, i.e., the possibilities and benefits that these applications provide for different age groups. This brings a requirement for further adjustment and improvement of the EGDI index.
- Objectifying weights and indicators included in constructing an individual index of the digital economy (Cruz Jesus et al., 2012). This is especially important to achieve scientifically justified and internationally comparable results of scientific research.
- Creating a global harmonized index of the digital economy. Having in mind the diversity and variety of indicators, authors have highlighted that it is desirable to create a unique composite indicator of digital development and competitiveness that would include various aspects of digitalization (Alam et al., 2018; Stankovic et al., 2022). However, it is difficult to expect this to be achieved in the short term because the prerequisite is the construction and standardization of internationally comparable databases.
- Digitalization and innovation. Digitization facilitates innovation activities and processes (Afonasova et al., 2019; Martínez et al., 2022; Pan et al., 2022; Huiyuan & Xiaomin, 2021; Xu & Li, 2022; Ionescu et al., 2022; Li et al., 2022; Tang et al., 2022). They lead to the accelerated creation of new products and services on the market and the disappearance of old ones. This creates the need for continuous improvement and upgrading of the existing indices of the digital economy. Scholars are also trying to find an answer to the research question of how the digitalization of the economy affects social innovation (Nagy & Somosi, 2022). In this area, there is also significant potential for improving the existing methodological framework.
- Digitalization and environment. In the last few years, the topic of the effect of digitalization on the environment has attracted the most interest among researchers (Firoiu et al., 2022; Han et al., 2022; Wang et al., 2022; Shen et al., 2022; Han et al., 2022; Bai et al., 2022; Li et al., 2022; Liu et al., 2022). Using the entropy value method and spatial Markov chain, Wang et al. (2022) constructed the development index of the digital economy. They applied the spatial Durbin model to analyse the impacts of digitalization on urban carbon emissions in China from 2011 to 2017. The authors created the digital economy index on a sample of data for 265 Chinese cities. The processes of globalization, integration, and technological progress, as well as the need for environmental protection impose the need to construct a unique index of the digital economy that will facilitate the research of the impact of digitization on the environment at the global level.

- Digitization and economic activity. In research on the contribution of digitization to economic activity, digital economy indices are often combined with other methodological approaches or there is often even a combination of several different digital economy indices (Alsaad et al., 2018; Tiutiunyk et al., 2020; Cahyadi & Magda, 2021; Binasova & Daneshjo, 2022; Baranauskas & Raišienė, 2022; Aly, 2022; Aziz et al., 2023). This opens up the space for improving and harmonizing the methodological approaches resulting from combining different methods or indices.
- The contribution of digital economy indices to creating short-term and long-term economic forecasts. Toh Hao et al. (2022) highlighted the significance of digital economy indices in creating economic forecasts. They concluded that digital economy indices make it possible to predict the short-term uncertainties of the economy. They can be useful as a short-term forecasting analytical tool for investors and policymakers to avoid unpredictable risks. Vovk et al. (2021) used the Digital Economy and Society Index (DESI) as a basis for creating forecasts of its main components: connectivity, human capital, use of the internet, integration of digital technology, and digital public services.

5. Conclusions

As a result of rapid technological development, the digital economy is making an increasing contribution to overall economic development (Wang & Chen, 2024). Therefore, there is a need for continuous improvement of the methodological framework for analysing the effects of digital technologies on economic processes and activities. In this context, indices of the digital economy play an increasingly important role. This paper systematically reviews the empirical literature on digital economy indices. The presented results of citation-based analysis show that the greatest contribution to the research area was made by Corrocher and Ordanini (2002) in the paper titled 'Measuring the digital divide: A framework for the analysis of cross-country differences'. In this study, constructing a synthetic index of digitalization, the authors propose a new model for measuring the digital divide within a set of countries or geographical areas.

The publication indexed in the ISI Web of Science database with the largest number of published articles on the researched topic is *Sustainability*. Also, the results obtained indicate a growing interest of scholars in digital economy indices. In addition to an overview of digital economy indices, the content analysis was primarily oriented on methodology development and its application in empirical research. Digital economy indices are continuously developed and upgraded with new methodological proposals (Corrocher & Ordanini, 2002; Wong et al., 2009; Gaaloul & Khalfallah, 2014; Ojanperae et al., 2019; Ferracane & van der Marel, 2020; Popov & Semyachkov, 2020; Goh, 2021; Li et al., 2021; Bai et al., 2022; Luo & Zhou, 2022; Toh Hao et al., 2022; Wang et al., 2022; Chen & Wu, 2022).

Parallel to the methodological development, scholars have tested, combined, compared, and evaluated various digital economy indices in empirical studies (Liu, 2022; Stavytskyy et al., 2019; Rakicevic et al., 2019; Li et al., 2020; Cruz Jesus et al., 2012; Park et al., 2015; Borowiecki et al., 2021; Imran et al., 2022; Karnitis et al., 2019; Skare et al., 2023; Milashovska et al., 2022; Melnychenko et al., 2021; Elmassah & Hassanein, 2022; Volkova et al., 2021; Banhidi & Dobos, 2023; Noja et al., 2022; Moroz, 2017; Wang et al., 2022; Wu et al., 2023; Shen & Zhang, 2022; Han et al., 2022; Lomakina et al., 2021; Marshall et al., 2020; Marino & Pariso, 2021; Szabolcs et al., 2022; Wang & Shi, 2021; Huang et al., 2022; Lyu et al., 2023; Chen et al., 2022; Chen & Wu, 2022).

The usefulness of digital economy indices is confirmed by their application in empirical studies. Research articles cover a wide range of topics, including the digitalization of public services, the digital divide across countries, the comparison of digital transformation in the European Union, the effects of digitalization on economic growth, the testing of digital financial inclusion, digitalization, and competitiveness, and the impact of the digital economy on innovation (Todoruț et al., 2018; Verkijika & De Wet, 2018; Surjit & Das, 2020; Fernández-Portillo et al., 2020; Ullah et al., 2021; Borowiecki et al., 2021; Vyshnevskyi et al., 2021; Liu, 2022; Soava et al., 2022; Olczyk et al., 2022; He et al., 2022; Zhou et al., 2022; Shen et al., 2022; Hurduzeu et al., 2022; Xu & Li, 2022).

Special attention of researchers in the last few years has been focused on the development of digital economy indices in areas where the role of digital technologies in the development of the green economy and environmental economy is tested (Bai et al., 2022; Li et al., 2022; Wang et al., 2022; Lyu et al., 2023).

The outcomes presented in this study offer insight into former research on digital economy indices in terms of methodological development and empirical findings. The final result of this review process is an advancement of the knowledge base for scholars and practitioners.

The limitation of this study stems from the fact that the research sample comprises only articles indexed in the Web of Science database. An additional limitation could arise from the fact that the collected research sample focuses exclusively on studies available on the internet. These limitations are somewhat mitigated by digitization processes being relatively recent and having a relatively short history.

It is valuable to emphasize both the research's theoretical and practical implications. Digitization is of great importance for improving and strengthening activities in all economic sectors. Numerous scientific studies have confirmed the positive contributions of digitization to economic growth, innovation, the efficiency of public administration, economic cooperation among countries, environmental protection, and energy efficiency. This study provides a complete picture of digital economy indices. From a methodological point of view, it covers the basic methodological features of digital economy indices, as well as the latest methodological proposals. The presented advantages and limitations of individual indices facilitate the selection and application of adequate indices in upcoming studies. The results presented in this research can indicate insufficiently explored topics, and thus, stimulate the creation of new research ideas. One of the biggest challenges for scholars in future research is how to construct and apply a harmonized index of the digital economy. Considering the different areas of application of digital economy indices, new methodological proposals can be expected about a unique index that could facilitate the research of the impact of digitization on the environment and energy efficiency.

In conditions of external influences and shocks such as trade restrictions and the migrant crisis, digitalization gains additional significance. In such circumstances, research endeavours aimed at developing a methodological framework such as digital economy indices gain even greater importance, not only in terms of the realization of new scientific contributions but also of broad theoretical and practical implications.

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