*electronics*

*Review*

# Green Information Systems—A Bibliometric Analysis of the Literature from 2000 to 2023

**Laura-Diana Radu * and Daniela Popescul**

Department of Accounting, Business Information Systems and Statistics, Faculty of Economics and Business Administration, Alexandru Ioan Cuza University of Iasi, 700505 Iasi, Romania; rdaniela@uaic.ro
* Correspondence: glaura@uaic.ro

**Abstract:** This review investigates the evolution of green information systems (ISs) based on an examination of the literature spanning the years 2000 to 2023. Using bibliographic analysis, a method that enables the study of a large volume of sources, this paper establishes connections among pertinent concepts in the green ISs field, outlining the authors' interests in the analysed period. Based on the identification of key trends, primary directions, interdisciplinary initiatives, and emerging areas, the assessment reveals that the interest in minimizing the negative impact of information and communication technologies (ICTs) on the environment is a relevant research topic, with significant evolution in the analysed period. On this basis, this study emphasizes the need for the integration of environmental protection in all stages of the IS life cycle and in all industries, a holistic approach we consider essential for the sustainable growth of the ICT-based societal domains.

**Keywords:** green information systems; bibliometric analysis; sustainability; green information and communication technologies (green ICTs)

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## 1. Introduction

The interest in environmental protection has substantially increased in recent decades, within the greater context of climate change. Awareness of issues related to natural resource consumption, global warming, and the rise in greenhouse gas emissions has led to the development of regulations aimed at restricting activities with potentially harmful impacts. The dependence of all relevant societal domains on information and communication technologies (ICTs) increases the need for hardware and software infrastructure, leading to an escalation of pollution both in the production phase and during use or post-disposal. Given that reducing the number of devices or their usage level is at least unlikely, if not deemed impossible, it becomes imperative to explore innovative solutions that can effectively alleviate their adverse environmental impact. This can be achieved by enhancing energy efficiency, developing low-carbon technologies, miniaturization, and efficient management of natural resources consumed throughout the entire ICTs' and IS' life cycles. Expressions such as green IT/ICT, green computing, and green or ecological information systems (ISs) are employed to reflect these concerns. These aim to limit the negative effects of ICTs on the environment, without restricting their usage. According to [1], green ISs transform organizations and society into more sustainable entities. They include both hardware equipment and software applications, as well as regulations, procedures, and human resources involved in their use or implementation.

In the last years, ICT has evolved through innovations in fields such as artificial intelligence (AI), big data, blockchain, virtual (VR) and augmented reality (AR), Internet of Things (IoT), etc. They enhance efficiency and facilitate the adoption of informed decisions, foreseeing a significant role for them in future carbon-neutral energy systems. The advancement of these technologies, considered disruptive in contemporary times, can be successfully utilized both in optimizing resource consumption [2] and in the identification and design of new, eco-friendly materials [3,4]. Their use is not without challenges, as it is accompanied by substantial consumption of resources that are not always environmentally friendly. By far, research in the field has primarily focused on the energy consumption impact of ICTs, with significant achievements in this direction [2,5,6], but green ISs extend beyond the scope of green ICTs. According to [7], green IS "refers to the objective of achieving energy efficiency and reduction in carbon emissions through "Greening *of* IT" i.e., creating Green IS products and reuse, refurbish and through "Greening *by* IT" as using IT to reduce environmental impacts". According to [8], green IS should stimulate environmentally sustainable decision-making and work practices through the shaping of beliefs and actions, as well as through result evaluation. The objective is to enhance ICT efficiency in a manner that enables a reduction in $CO_2$ emissions and the consumption of non-renewable resources, ensuring the sustainable development of society.

The evolution of ICT in recent years provides versatile opportunities to persuade citizens about the environmental benefits brought by green ISs and to encourage them to change their behaviour. Recent studies have explored various aspects of green ICT and less of green IS. The context created by the COVID-19 pandemic has raised numerous questions. The number of travels decreased during lockdown periods, but commercial transportation intensified. People worked from home, continuing to use various devices. Energy consumption in companies decreased, but household consumption increased. Wang and Huang studied the impact of the COVID-19 pandemic on sustainable development goals [9].

In the context of the multiple paradigm shifts based on digitalization and (autonomous) communication between various devices, such as smart cities, industry 4.0, smart agriculture, Fintech, telemedicine, e-learning, etc., the development of minimally invasive technologies for society is essential.

For a better understanding of the landscape of the green IS field, this paper sets out the answer to the following research questions:

RQ1: Which are the most impactful sources of the literature and who are the most representative authors?

Motivation: It is imperative to discern the principal sources of the literature, specifically scientific documents, and their respective authors, to establish dependable and resourceful references.

RQ2: What is the actual status and the potential trend in the research in green ISs?

Motivation: The preceding research topics lay the foundation for future research directions and highlight the research gap, providing insightful information for trend prediction.

RQ3: What are the connections between the currently available publications and the evolution of the addressed topics?

Motivation: The interconnection among topics explored in previous research may serve as a primary catalyst for the evolution of both established and emerging directions within the realm of green IS, given its multidisciplinary nature.

The main motivation for the research questions arises from the omnipresence of IS in companies, institutions, communities, cities, etc., functioning increasingly as a web of interconnected subsystems based on ICT. The number of IoT-connected devices has significantly increased in recent years and is estimated to almost double from 15.1 billion in 2020 to more than 29 billion in 2030 [10]. These must synchronize, collect, and provide accurate, real-time information, being integral parts of the same system. However, the context in which they achieve this should be minimally invasive to the environment throughout all stages of the life cycle, thereby shaping the concept of green IS. This can only be accomplished through collaboration between academia and industries. In consideration of this, the research identifies the most impactful topics and trends to support the development of directions that bring added value.

The remainder of this paper is organized as follows: Section 2 presents the materials and methods used to conduct this study. Section 3 reveals the results of the bibliometric analysis and addresses each of the research questions. Section 4 discusses the results and main limitations. Finally, Section 5 summarizes the major contributions of this study.

## 2. Materials and Methods

To conduct this study, we chose bibliometric analysis as the research method. We deemed this approach suitable for finding answers to our questions as presented in the previous section. Bibliometric analysis uses statistical methods to evaluate the evolution of a particular research area [11]. It provides the opportunity to analyse a large number of publications, the correlations between concepts used in a specific domain, the most productive journals, countries, and authors, and the most popular themes and articles.

### *2.1. Data Collection*

A comprehensive literature search was conducted across the Scopus database. We selected this database because of its comprehensive interdisciplinary coverage, a crucial element for effective research. The use of Scopus for bibliometric analysis is highly valuable.

Its comprehensive coverage of trustworthy peer-reviewed research not only strengthens the credibility of findings but also contributes to a more profound comprehension of the research landscape within a given field. Additionally, the consideration of its reputable standing as a reliable source for academic research across diverse fields, including ITC, environmental studies, and sustainable development, further influenced our decision. Prior to beginning data collection, we conducted an initial literature scan to identify common, relevant, and emerging concepts in the research field. This step provided a foundational understanding of the themes prevalent in the field, helping us to identify relevant terms. Finally, the research phase included the following terms "green information system", "ecological information system", "sustainable information system", and "clean information system". The search was limited to articles in English published from 2000 to 2023. The search strategy is presented in Table 1.

**Table 1.** Search strategy for extracting the database of scientific articles for the review.

| Search Strategy | |
|---|---|
| Keywords | "green information system" OR "ecological information system" OR "sustainable information system" OR "clean information system" |
| Database | Scopus |
| Inclusion criteria | Search within the title, keywords, and abstract of the following document types: articles, conference papers, book chapters, reviews |
| Exclusion criteria | Conference review, book, editorial, note, duplicate |
| Period explored | 2000–2023 |
| Language | English |

Following the pre-set limitations, the following query was applied to the title, abstract, and keywords: (TITLE-ABS-KEY ("green information system") OR TITLE-ABS-KEY ("sustainable information system") OR TITLE-ABS-KEY ("clean information system") OR TITLE-ABS-KEY ("ecological information system")) AND PUBYEAR > 1999 AND PUBYEAR < 2024 AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "ch") OR LIMIT-TO (DOCTYPE, "re")).

The search yielded 325 documents. Following the initial search, we embarked on a detailed multi-step process to refine the dataset. While Scopus is renowned for its rigorous procedures that help minimize the presence of duplicates, given its extensive and intricate nature, we conducted a meticulous verification of the dataset to eliminate papers with missing information, thereby ensuring the accuracy and completeness of our analysis. We scrutinized the title, abstract, and keywords of each document to ascertain its relevance to the selected topic. To minimize bias, both authors independently conducted this stage of manual review of articles within the dataset. This process resulted in retaining 318 studies for further analysis. Documents proposed for elimination were assessed by both authors, and decisions were made collaboratively.

### 2.2. Research Methods and Tools

This paper primarily employed the bibliometric method. The method has two stages as follows: performance analysis and science mapping [12]. In the initial phase, an analysis was conducted on the principal journals, proceedings, and books featuring articles related to the studied topic. Subsequently, in the second stage, this study delved into elucidating the dynamics and evolution of the research, along with identifying key trends. This was accomplished by establishing connections between authors and conducting analyses on co-citations and co-occurring terms. The co-citation analysis explored the research field, elucidating its knowledge structure through an examination of pairs of documents co-cited. The co-word analysis scrutinized sets of shared terms among documents, an operation that enables the mapping of these terms based on the key inputs' interaction [13]. Based on these, the main topics of interest were identified, the evolution of knowledge in the field was analysed, and future trends were outlined.

Bibliometrix, an R package, was used to conduct the examination. Bibliometrix was developed by [14] and is "an R statistical package for analysing and visualizing the bibliometric data from Web of Science and Scopus databases". The selection of Bibliometrix was based on the success of using this R package in previous bibliometric studies, as demonstrated by [6], who evaluated the potential of artificial intelligence in advancing clean energy technologies in Europe.

## 3. Results

### 3.1. Overall Research Overview

Quantifying publications provides crucial information for estimating the popularity of fields or specific topics within a research domain. The measurements can take various forms, including the number of articles, citations, publications in journals, and collaborative articles. Starting at a macroscopic level, Table 2 offers information on the research landscape from 2000 to 2023, capturing the scope and depth of academic contributions in the field of green ISs. The presented values allow for contextualizing the volume, diversity, and collaborative nature of research in the analysed domain. Understanding the distribution of document types, the degree of collaboration among authors, and the predominant keywords enables the creation of a comprehensive picture of the research dynamics during the mentioned period.

**Table 2.** Overview of research landscape from 2000 to 2023 in green IS field.

| Description | Results |
| --- | --- |
| MAIN INFORMATION ABOUT DATA | |
| Timespan | 2000:2023 |
| Sources (journals, books, etc.) | 229 |
| Documents | 318 |
| Annual growth rate % | 8.48 |
| Document average age | 7.64 |
| Average citations per doc | 16.76 |
| References | 15,334 |
| DOCUMENT CONTENTS | |
| Keywords plus (ID) | 1661 |
| Author's keywords (DE) | 887 |
| AUTHORS | |
| Authors | 704 |
| Authors of single-authored docs | 41 |
| AUTHORS COLLABORATION | |
| Single-authored docs | 50 |
| Co-authors per Doc | 3.02 |
| International co-authorships % | 21.38 |

**Table 2.** *Cont.*

| Description | Results |
|---|---|
| DOCUMENT TYPES | |
| Article | 147 |
| Book chapter | 18 |
| Conference paper | 140 |
| Review | 13 |

A large number of citations, along with the annual growth rate, reflects a continuous increase in interest in the analysed topic. This, coupled with international co-authorship, highlights that this interest is not local; it transcends national boundaries, with efforts in the field of environmental protection, including the development and utilization of green ISs, extending globally. Additionally, the low number of single-author articles reflects the shared concerns and collaborative effort of multiple authors on the selected topic for analysis. Another noteworthy aspect is the small number of reviews compared with the number of articles, indicating the academic community's inclination towards primary research.

### *3.2. Impactful Journals, Authors, and Countries*

The distribution analysis reveals that approximately 25% of the articles are published in 18 journals, books, or proceedings. The impactful journals, along with their corresponding number of publications, number of local citations, h-index, g-index, and m-index, are listed in Table 3. Local citations count the number of citations a document receives from other articles within the dataset. The h-index measures both the productivity and impact of an author's published articles [15] calculated as the number of published articles $h$ that are cited in other publications at least $h$ times. It is considered one of the most important indicators for evaluating journals. The g-index is the (unique) largest number such that the top $g$ articles received (together) at least $g^2$ citations [16]. The m-index is calculated by dividing the h-index by the number of years since the first publication, being considered an "indicator of the successfulness of a scientist" [17]. It allows for comparisons between researchers with different seniority.

**Table 3.** Top ten journals by the number of local citations.

| Journal | Total Citations | h-Index | g-Index | m-Index | No. of Publications |
|---|---|---|---|---|---|
| *Information and Management* | 359 | 2 | 3 | 0.167 | 3 |
| *Environmental Science and Pollution Research* | 240 | 1 | 2 | 0.125 | 2 |
| *Communications of the Association for Information Systems* | 228 | 5 | 8 | 0.417 | 8 |
| *Industrial Management and Data Systems* | 193 | 2 | 2 | 0.154 | 2 |
| *Journal of the Association for Information Systems* | 171 | 2 | 2 | 0.222 | 2 |
| *Information Systems Frontiers* | 168 | 4 | 4 | 0.333 | 4 |
| *Information Systems Journal* | 148 | 3 | 3 | 0.333 | 3 |
| *International Journal of Production Research* | 144 | 1 | 1 | 0.111 | 1 |
| *Management Science* | 137 | 1 | 1 | 0.143 | 1 |
| *International Journal of Information Management* | 130 | 3 | 4 | 0.375 | 4 |

The largest number of articles addressing topics related to green IS were published by the Association for Information Systems, followed by Springer and the Institute of Electronics and Engineering. Figure 1 illustrates the publishers that have published more than ten articles on the subject analysed in this study.

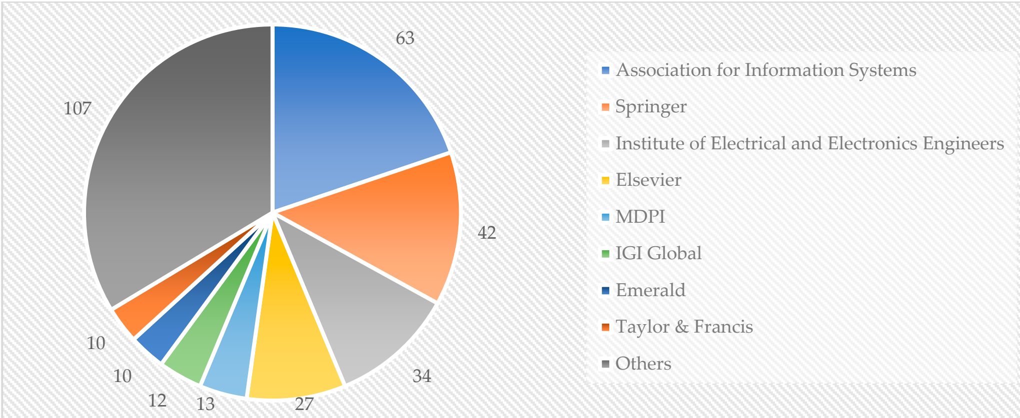


**Figure 1.** Number of papers per publisher (for publishers of more than ten papers).

Figure 2 presents the most productive authors during the analysed period along with the number of citations obtained each year. As observed, the oldest publication in the top ten was published in 2008, but 50% of the articles were published after 2016. This demonstrates that the interest in the field, as well as the most notable achievements, are recent. The size of the circle is proportional to the number of articles published per year, and the colour intensity reflects the total number of citations per year.

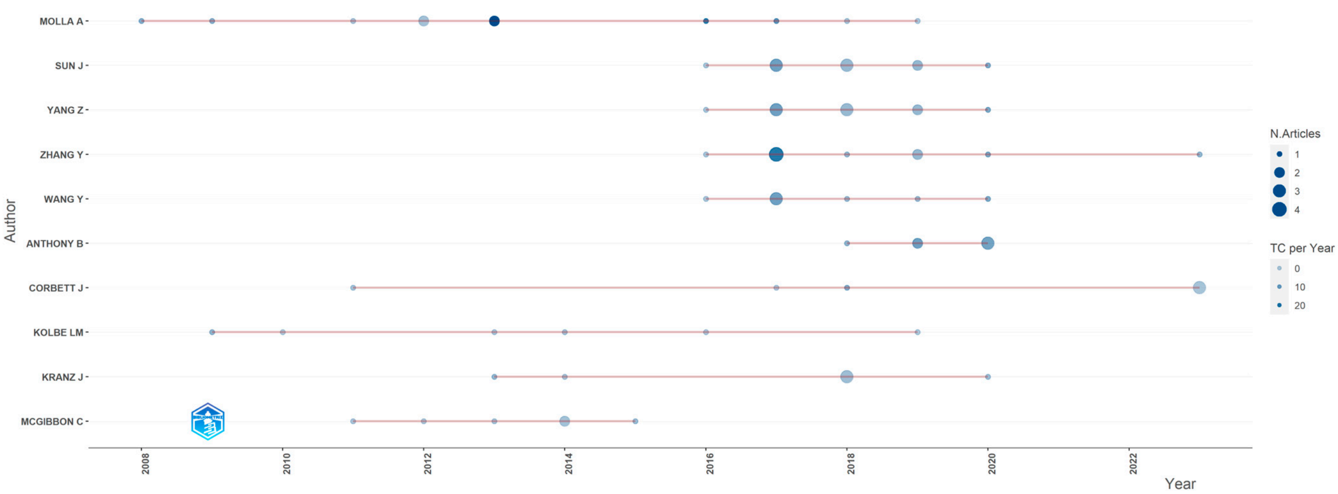


**Figure 2.** Productivity of authors over time (TC stands for times cited).

Table 4 presents the top ten authors, along with the number of articles they authored, the total citations received, and the research topics related to green ISs that they have studied. Molla A. dominates the ranking with 11 articles published on the topic of green IS as an author or co-author in the period 2008–2019, accumulating the highest number of citations, namely, 840.

The publication of articles was a team effort, outlining several groups of authors who collaborated. Figure 3 presents these groups. The thickness of the lines indicates the level of collaboration between authors. The thicker the line, the greater the number of articles published together. For example, Zhang Y., Sun J., Yang Z., and Wang Y. (purple) co-authored several articles. Another cohesive research group characterized by frequent collaborations consists of Molla A., Gholami R., and Watson R. T. (blue). They developed collaborations with other authors sharing similar research interests. A third notable group includes Kolbe L. M. and Kranz J. (red). In other cases, researcher groups collaborating for the publication of articles on the topic of green IS consist of two or three authors.

**Table 4.** Top ten authors.

| Author | No. of Articles | Total Citations | Research Topics Related to Green IS |
|---|---|---|---|
| Molla A. | 11 | 840 | social enterprise, environmental strategies, data centres, environmental performance, organizational motivations, environmental enterprise systems, green IS practices |
| Sun J. | 10 | 166 | green supply chain, green culture and innovation, digital innovation, corporate sustainability, employees' green behaviour |
| Zhang Y. | 10 | 245 | green supply chain, corporate sustainability, green culture and innovation, employees' green behaviour |
| Yang Z. | 10 | 166 | green supply chain, digital innovation, corporate sustainability, green culture and innovation |
| Wang Y. | 7 | 164 | green supply chain, digital innovation, corporate sustainability, green culture and innovation |
| Corbett J. | 6 | 71 | strategies, machine learning, education, corporate sustainability, persuasive systems, smart grid |
| Kolbe L.M. | 6 | 90 | sustainable communities, GHG emissions, sustainable information system management |
| Kranz J. | 6 | 88 | pro-environmental behaviour, leadership, logistics, greenhouse emission |
| Bokolo A. | 6 | 134 | green IS practices, green IS diffusion, education, corporate ecological responsibility, organizational performance |
| McGibbon C. | 6 | 68 | education, green building, key drivers of green IS |

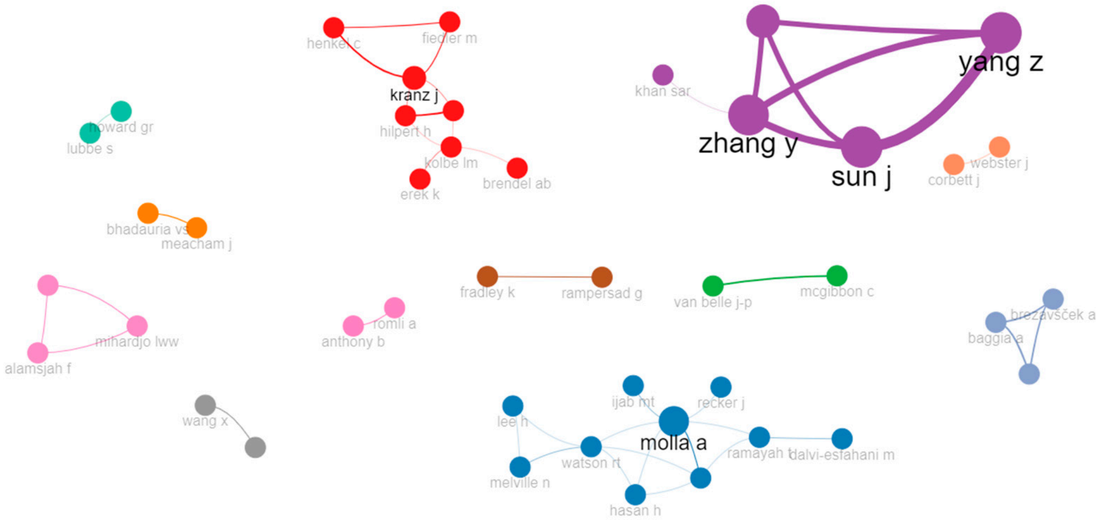


**Figure 3.** Collaboration network.

Table 5 presents the top ten countries from which authors have published the most articles on green IS during the analysed period. An article is attributed to a country if at least one of the authors is from that country. Consequently, an article may be attributed to multiple countries if it is the result of collaborations conducted on a global scale.

The table also presents the number of citations of the works published in the top ten countries, as well as the frequency of international collaborations. A small percentage of the publications result from collaborations among authors from diverse countries, despite the fact that numerous publications have more than one author, indicating the existence of various research groups (Figure 2).

**Table 5.** The most productive countries based on the frequency of publications.

| Country | No. of Articles | Total Citations | Int. Co-Authorship |
|---|---|---|---|
| Germany | 152 | 280 | 7.2% |
| USA | 117 | 348 | 3.1% |
| China | 79 | 741 | 7.2% |
| Australia | 74 | 357 | 4.1% |
| Malaysia | 41 | 240 | 2.8% |
| Indonesia | 38 | 39 | 2.2% |
| South Africa | 32 | 66 | 1.9% |
| India | 30 | 71 | 3.1% |
| United Kingdom | 29 | - | 1.6% |
| Pakistan | 28 | 64 | 1.3% |

### *3.3. Prolific and Impactful Documents*

The popularity of a paper, evaluated by the number of citations, is influenced by various factors, such as the impact of the journal in which it was published, the number of years since publication, the extent to which the author/authors are known in the field, etc. However, for the analysed topic, newer works have more citations than older ones. In the Table 6, the top ten documents are ranked by the number of citations. The Global Citation Score represents the number of citations received by a work across the entire Scopus database. It provides an overview of the impact a specific work has in the analysed field. It can be observed that nine out of ten works are from the second half of the analysed period, and two of them are very recent, from 2021. Concerns for environmental protection through ICT have intensified recently due to its significant degradation, increasingly visible climate changes, and the reduction in non-renewable resource consumption.

**Table 6.** Top ten most influential documents.

| Article | Research Topics Related to Green IS | Global Citation Score |
|---|---|---|
| [18] | Green IS adoption, environmental performance, personality traits, institutional theory, coercive and mimetic pressure | 336 |
| [19] | Green supply chain practices, organizational performance, eco-design processes, environmental performance | 239 |
| [20] | Climate change, design science, IoT, green IS barriers | 161 |
| [21] | Green supply chain management practices, organizational performance, environmental performance, environmental collaboration and monitoring | 153 |
| [22] | Green product design, green supply chain processes, green purchasing and manufacturing, economic and environmental performance | 144 |
| [23] | Energy conservation, decision-making, water conservation, environmental behaviour, behavioural changes, real-time feedback, policy intervention | 137 |
| [24] | Green supply chain practices, competitive advantage, internal environment management, economic, environmental, and organizational performance | 121 |
| [25] | Blockchain technology, sustainable and green supply chain, big data analytics, organizational performance, operational, environmental, and economic performance | 116 |
| [26] | Business transformation, energy informatics, future development of IS discipline | 109 |
| [27] | Green IT, corporate social responsibility, drivers of green IT, green IT readiness, green IT context | 101 |

The analysis of correlations among cited articles can highlight interesting aspects regarding the topics addressed by various research groups or individual researchers. Figure 4 shows the bibliometric historiography using the science mapping tool, Bibliometrix [28]. It first generates the historical direct citation network from the largest citation network and then visualizes the network in chronological order [29].

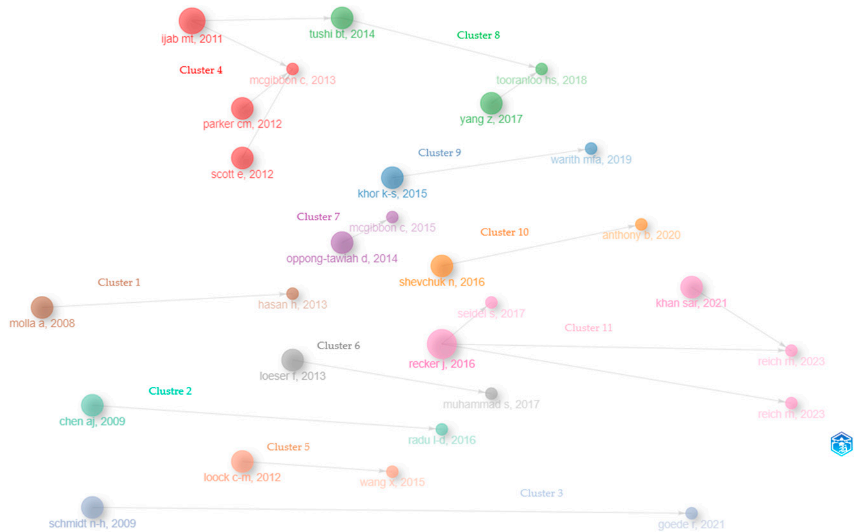


**Figure 4.** Bibliometric historiography [8,25,27,30–54].

In the first cluster (Cluster 1), the research addresses topics related to adopting a model that allows for mitigating the negative impact of ISs on the environment, considering technologies, systems, and applications that provide opportunities for solving environmental problems, as well as the issues they generate.

In the second cluster (Cluster 2), concerns focus on the role of green IS in organizations and institutions and the necessity or pressures exerted for their adoption.

The third cluster (Cluster 3) frames the role of green ICT in business intelligence, addressing aspects related to energy conversion, corporate social responsibility, and critical system thinking. These aspects can contribute both to the sustainability of the business information systems themselves and the adoption of the organization's strategic decisions.

The fourth cluster (Cluster 4) explores aspects related to the integration of green IS into university curricula to stimulate interest in green values from the early stages of studying the field.

The necessity of an implementation framework for green IS, as well as the elements influencing its efficiency, such as population dynamics and statistics, personal characteristics, social norms, and population distribution, are analysed by authors in the fifth cluster (Cluster 5), alongside potential future development directions.

Cluster 6 includes theoretical research on a green design framework to identify the main measures and practices that could contribute to limiting the impact of ISs on the environment and their contribution to sustainable development through green ISs.

Cluster 7 encompasses research addressing more concrete issues related to solutions for reducing the negative effects of ISs on the environment. This includes a reduction in energy consumption and $CO_2$ emissions, as well as the pro-environment behaviour of human resources as a component of IS. Additionally, the importance of introducing the study of aspects related to environmental sustainability into university curricula is emphasized to support the development of key competencies in sustainability and lead to real-world impacts.

Specific concerns of certain industries and practical examples of green IS are addressed in Cluster 9, as well as practical business opportunities for ICT managers of socio-economic-oriented organizations.

Cluster 10 primarily addresses aspects related to behaviour change by employing persuasive techniques throughout the design, implementation, and utilization of ISs to foster the development of green solutions.

In the last cluster, Cluster 11, the research discusses current issues related to the circular economy as a necessity for the development of smart IS design, blockchain technology, and green supply chains. Aspects related to IS architecture, requirements engineering, and product and material passports are also treated as instances of green ISs.

### 3.4. Trend Topics

In the context of the rapid evolution of ICT, it is essential to understand the trends and changes in the green IS field in both the academic and business environments. An analysis of the frequency and temporal distribution of topics addressed in the literature can provide insights into the domains that have garnered attention in recent decades, allowing for estimations of future directions. Figure 5 presents the main topics studied, their frequency, and their distribution over the analysed period. The three quartiles and the median enable us to obtain an overview of the topics addressed over time, identify patterns, and discern changes in research directions. Common terms and country names have been removed to highlight relevant topics.

- Ecology and environmental protection topics began to be primarily studied in the early part of the analysed period but persisted over time, with the median in 2001 and 2012, respectively.
- Information technology, innovation, management information systems, economics, environmental sustainability, and environmental impact topics gained prominence, especially during the period 2011–2017, highlighting interest in various aspects of green ISs, including technical, economic, and environmental considerations.
- Supply chain and design were in the spotlight between 2013 and 2018, with the median at the beginning of the period in 2014.
- Environmental technologies and resource-based views drew attention for a short period, approximately between 2012 and 2017.
- Energy utilization and efficiency and greenhouse gases are more specific issues associated with the development and use of hardware and software applications, and they were in focus during the period 2013–2020, indicating a growing interest in the correlation between digitalization and environmental issues.
- Sustainable development, environmental management, and competition are topics discussed more recently, in the period 2013–2020, with the median in 2017. Green ISs have thus been included in a broader topic of sustainable development from both economic and environmental perspectives.
- Behavioural research was associated with green ISs for a very short period, specifically 2016–2019.
- Climate change and green computing were among researchers' concerns in the periods 2014 and 2015, respectively, and extended until 2021.
- Decision-making, information management, and information use drew attention around 2019, highlighting interest in a less technical aspect of ISs.
- IoT and decision theory complete the landscape of green IS research, being, alongside information management and information use, subjects that persist to the present.

The topic trends analysis reflects a diversity of subjects and concepts associated with research in the field of green IS, highlighting its complexity and various aspects. It is linked to general environmental issues (such as ecology and environmental protection, environmental sustainability, and environmental impact) as well as specific initiatives aimed at reducing negative effects on the environment through improved energy efficiency, addressing climate change, and reducing greenhouse gas emissions. Additionally, managerial-specific topics (such as economics, information management, and information use) with an impact on green IS, as well as technical aspects (such as green computing, and environmental technologies), have been analysed. The extracted documents in the dataset cover various dimensions of green IS, ranging from technical aspects involving the direct and indirect impact of ICT to those addressing behavioural change. Additionally, the research addresses contemporary, quantifiable subtopics that are continuously being evaluated and improved upon, such as energy consumption, resource consumption, or greenhouse gas emissions.

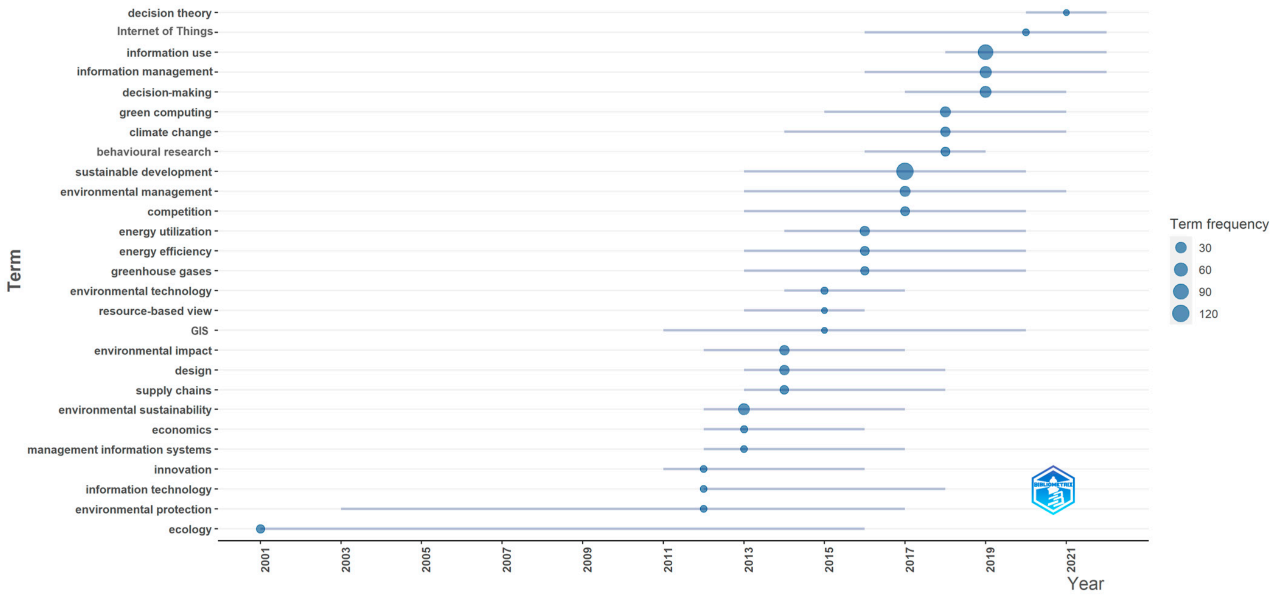


**Figure 5.** Trends in the key topics in green ISs between 2000 and 2023.

### 3.5. Factorial Analysis

Factorial analysis is a classical statistical technique [55] that can be used to identify key factors influencing scientific production in a specific field. It was introduced by [56] and provides a deeper insight into the characteristics of datasets by identifying patterns and associations between different elements. Figure 6 presents the factorial analysis of articles published about green ISs in the period 2000–2023 using Multiple Correspondence Analysis (MCA) generated from Bibliometrix. This method allows for analysis of the pattern of relations between a set of categorical variables. The distance between words is proportional to the number of cases in which they have been used together in the same articles. Words are close to each other if they have been used together in numerous articles; they are distant from each other if they appear together in a small portion of articles [57]. The cluster closest to the centre is the core cluster. The goal is to understand how different concepts are connected in various articles within the dataset. Words in the same cluster are frequently used together. Two categories are represented as Cluster 1 (red) and Cluster 2 (blue) to identify connections.

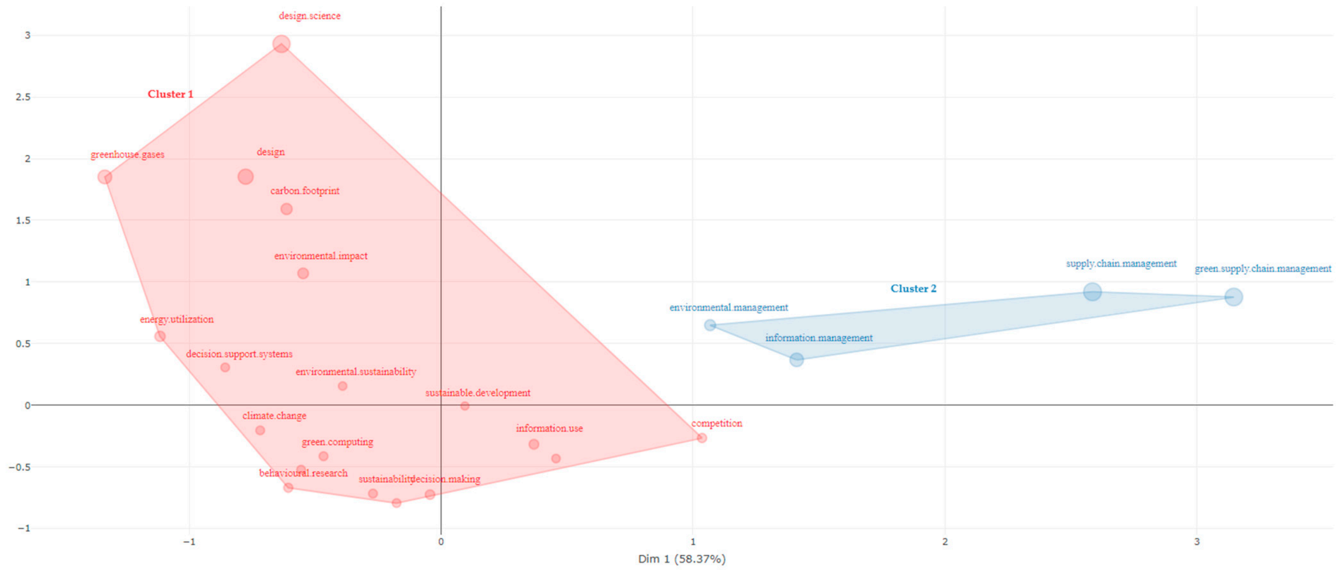


**Figure 6.** Factorial map of most frequent keywords.

The figure shows keywords frequently used together by authors. From the observation of the bibliographic results obtained, two dominant clusters were identified in the proposed field of research. Cluster 1 is broader and addresses quite diverse aspects such as carbon footprint, energy, behaviour, etc., while Cluster 2 deals with more specific issues, namely, green supply chain management (SCM), information management, and environmental management. Factorial analysis was conducted based on keywords plus using the MCA method with the following parameters: number of terms = 30 and number of clusters = 2.

Green IS adoption brings benefits both for the environment and organizations. However, their success is conditioned by the involvement of users positioned at all hierarchical levels. In the first cluster, green ISs are studied from multiple perspectives, highlighting the complexity of the concept and its significant economic and social impact. Zampou et al. argue that energy and carbon management systems, as a class of green IS, can significantly contribute to increasing environmental sustainability in organizations and across supply chains [58]. They provide a favourable context for reducing the negative impact on the environment. In this context, the authors develop ISs design theory based on the following six system components: data collection, energy monitoring, supply chain coordination, energy and carbon management systems workflow engine, reporting, and carbon footprint estimator. The development of contextual and sustainable ISs, where energy consumption reduction is achieved using adaptive technology and the design of context-aware processes and data, constitutes a development direction in the case of green ISs [59,60].

For specific domains such as aviation [37,61], automotive [62–64], agriculture [65], healthcare [66], and banking [67], specific issues (sets of practices or technologies) have been addressed to reduce the negative impact of ISs on the environment, mainly through a reduction in energy consumption. Equipment and software are only part of the issue in the adoption of green IS. Individual behaviour and attitudes are also important aspects that influence change. These are determined by demographic and socio-economic characteristics, but also by psychological and factual knowledge about the environment [68,69] or by institutional pressure [48]. Motivations can vary based on the hierarchical position of the individuals desiring the change. A management-level study identified the following psychological drivers, presented in order of their influence: monetary cost–benefit assessment, green IT/IS attitude, awareness of consequences, personal norms, self-efficacy, self-transcendence, openness to change, ego strength, locus of control, ethical climate, positive affect, the ascription of responsibility, and subjective norms [70]. The reasons for adopting green ISs can be delineated not only based on individuals' roles within the company but also by their source in extrinsic and intrinsic motivations, being determined by the organization's strategy and employees' beliefs [71].

Creating a framework for adopting green ISs in universities is a dynamic subject primarily due to technological evolution but also due to socio-economic and legislative changes [69,72,73]. Resource consumption on university campuses is significant and generates high costs. The Case-Based Reasoning technique can be used to assimilate green IS in university campuses and other communities to make them more ecological. The technique is based on the following determinants: people, management, IT infrastructure, external pressure (generated by regulations, economic or social context, etc.), IT strategy, and information availability, all influencing each stage of the IS life cycle [73]. Education for green IS should start in the early stages of studying this concept by introducing it into university curricula. Scott et al. undertook an educational project in the green IS field with five student groups at the University of Cape Town, mainly focused on monitoring resource consumption (electrical power and paper) [32]. Such initiatives create the possibility of using campuses as living laboratories for implementing pilot projects related to sustainability. Initiatives in this direction are neither unique nor new, as shown by a study conducted by [74], which analyses the green IT/IS curriculum recently introduced by leading universities and organizations.

Organizations' strategies in adopting green IS have been classified into proactive or defensive strategies and reactive or assertive, aggressive strategies [75,76]. In the first case, companies adopt green IS as a reaction to changes or threats from the external environment, while in the second case, companies act before motivations generated by external factors arise [77]. Legal regulations regarding products or processes, actions by competing companies, limited access to certain natural resources, etc., represent external motivations for adopting green IS. Among internal motivations, we find ecological responsibility, the desire to attract new customer categories, increasing competitiveness, increasing revenues and decreasing costs, etc. Management involvement increases the likelihood of adopting green IS, and the existence of an environmental strategy will positively influence the organization's "green" beliefs and will lead to sustainable IS practices.

Green ISs bring numerous benefits to the environment and companies. They create competitive advantages and positively influence organizational performance [78–80], generate new opportunities, and reduce risks and costs [37]. Eco-design can be used to improve the quality of products delivered to customers [81]. It can enhance the manufacturing process and purchasing, and both will influence manufacturing performance. Integrating sustainable thinking and performance is essential for organizations. IS supports the creation of a holistic view of economic, social, and environmental information managed within the company, but it should do so in a non-invasive manner. Sustainability-supporting initiatives should be implemented at the micro-level by each employee and group, understanding the impact of their daily actions, up to the macro-level through decisions made by senior management [82]. Green ISs are part of the circular economy, which involves sharing, renting, reusing, repairing, refurbishing, and recycling existing materials and products to extend their life cycle as much as possible. However, transforming business processes is necessary to integrate green practices, technologies, and rules, as well as performance indicators related to environmental impact, and optimize information flows [8]. The product passport provides important information for adopting an environmentally friendly strategy regarding the full or partial reintegration of a product into the circuit at the end of its life or its recycling. Considering that everything around us is currently "smart" (smart home, smart city, smart country, etc.) and that this involves the existence of numerous interconnected devices, adopting a strategy that considers the ecological dimension is essential. Each organization or institution, as well as a family, functions as a system integrated into a larger system, that of the community in which it operates. Each city operates as a system composed of multiple subsystems. Similarly, each country or region functions in a comparable way. All the mentioned entities depend on limited natural resources and increasingly on technology. Therefore, there should be an interest in green IS and involvement in adopting and implementing innovations that support them and make them minimally invasive in terms of environmental impact, both at the micro-level (individual, family) and the macro-level (city, country, region, etc.). The authors of [83] identify the following five levels of sustainable information and their stakeholders: product or service (product producers and consumers), individual (citizens and employees), functional (function management team, organization management, and employees), organizational (executive team, shareholders, citizens, regulators, supplies, and consumers), and regional/city (public administration, policymakers, politicians, corporations, citizens, and regulators).

The concept of Ultra-Large-Scale Green IS is used for the socio-technical open systems of systems that are different from traditional ones in terms of scale, complexity, and urgency [84]. They allow for the integration of all subsystems within smart cities, ensuring citizens easy access to information and resources. The holistic architecture of such systems is much more complex given that many stakeholders are unknown, design objectives have not been defined, the system's behaviour is dynamic, and collaboration between clients and producers is crucial to achieving financial, social, and environmental objectives, known as the triple bottom line. These refer to companies' interest in establishing both an economic bottom line and social and environmental bottom lines [83]. Involvement can manifest itself in optimizing solutions for recycling equipment at the end of its useful life, significantly reducing environmental pressures [85], and designing and investigating innovative methods and techniques supporting a better sustainability of business activities [86].

In the second cluster, concerns are grouped around the following four concepts: SCM, green SCM, environmental management, and information management. ISs serve as important support tools for sustainable SCM practices [87]. They bring benefits to the organization, suppliers, and customers. The integration of green SCM and green IS is likely to have synergistic effects on corporate sustainability and performance [80,88]. Integrating environmental protection concerns into the stages and tools used as part of SCM will contribute implicitly to reducing the negative effects of IS while positively influencing technological performance [89,90].

### 3.6. Thematic Analysis

The results obtained through thematic analysis highlight the topics associated with green IS and allow for the identification of patterns for making predictions regarding the evolution of research in the field. Table 7 presents the main clusters identified based on keywords and a series of calculated indicators for each of them.

**Table 7.** Clusters resulting from thematic analysis.

| Cluster | Callon Centrality | Callon Density | Rank Centrality | Rank Density | Cluster Frequency |
|---|---|---|---|---|---|
| sustainable development | 5.04 | 25.92 | 9 | 5 | 621 |
| systems analysis | 0.13 | 33.22 | 3 | 8 | 37 |
| ecology | 0.73 | 35.33 | 6 | 9 | 44 |
| commerce | 0.56 | 24.21 | 4 | 3 | 23 |
| innovation | 0.60 | 18.06 | 5 | 1 | 12 |
| SCM | 2.14 | 29.04 | 8 | 6 | 109 |
| sustainability | 0.89 | 30.23 | 7 | 7 | 73 |
| developing countries | 0.10 | 20.00 | 2 | 2 | 5 |
| information services | 0.00 | 25.00 | 1 | 4 | 4 |

The identification of clusters was carried out by applying the walktrap algorithm, relying on thematic similarities and keyword co-occurrence. The algorithm determines the frequency of occurrence of keywords in the same articles. Used in graph theory, it identifies communities in a large network through random walks. These communities are then used to calculate the distance between nodes, which, in this case, are the keywords. Subsequently, groups are created, with each group consisting of highly connected nodes. The analysis was conducted based on keywords plus, number of words = 250, and minimum cluster frequency = 15. Centrality reflects the theme's relevance, and density reflects the theme's development [91]. Callon centrality represents the importance of a group in the entire network, with higher values indicating more influential groups. In this case, sustainable development and SCM are the most central and influential, playing a key role in research in the field. Callon density measures the cohesion within the group. Clusters with high Callon density contain themes that are closely related, as is the case with ecology, system analysis, and sustainability. Rank centrality prioritizes clusters based on the relative importance or position of a theme or subject compared with the others analysed. Lower values indicate higher importance or cohesion. Rank density provides information about the importance of a node based on the number of connections it has with other nodes [92]. Lower values indicate greater dispersion or diversity of themes. Cluster frequency calculates the interest in research themes within a group. Themes with higher values of this indicator are more frequently encountered in the articles in the dataset. Sustainable development and SCM are positioned in the top two spots, being the most frequently analysed in terms of correlation with green IS.

Figure 7 reflects the level of development and relevance of the topics related to green IS. In the upper part of the graph, in the left quadrant, there are niche topics, less addressed or developed, while in the upper right quadrant, there are motor themes or leading themes. In the lower part of the graph, in the left quadrant, there are emerging or declining topics, while in the right quadrant, there are fundamental themes.

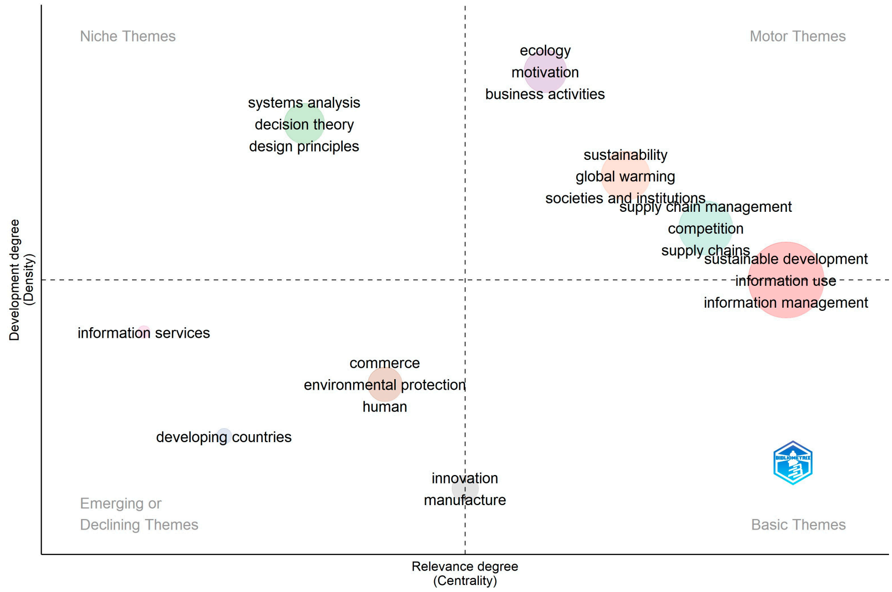


**Figure 7.** Clusters resulting from thematic analysis.

The representation from the previous figure is useful for identifying and understanding the most important themes and research directions in the analysed field. Our bibliometric analysis reflects both singular themes and interesting connections. The system analysis cluster combines concerns from the decision theory field but also design principles aimed at reducing the negative effects of IS on the environment throughout its entire life cycle. The ecology group includes diverse aspects that refer to both motivation and business activities, connecting environmental protection concerns to both subjective, psychological aspects and objective, economic ones. In the sustainability cluster, issues related to global warming are addressed from both a social and institutional involvement perspective. In the SCM cluster, the emphasis is on the competitive advantages that green IS brings. The sustainable development group includes concerns regarding economic, social, and environmental sustainability studied together with the benefits and the need for optimizing information management in the context of easy access to a large volume of data and the technologies required for their efficient processing. Another cluster associates concerns related to business activities, human behaviour, and the possibility of conducting them in the least environmentally invasive manner. Innovation in the field is primarily dedicated to production activities, covering concerns related to obtaining innovative devices within innovative production processes that have low consumption of non-renewable resources in a production process with minimal negative effects. In the end, the information services cluster addresses specific issues related to the collection and processing of information in a way that ensures that IS is as close as possible to the concept of green. The developing countries cluster focuses on analyses conducted in countries in this category in the context of major environmental issues they face because of financial and educational limitations, as well as the lack of legislation in the field.

### *3.7. Thematic Evolution from 2000–2012 to 2013–2023*

Table 8 presents the temporal evolution of relationships between the studied topics between 2000–2012 and 2013–2023 (first ten rows). This analysis reveals how different research themes have been connected and developed over delimited periods [93]. In the first column (From), subjects from the initial period are represented, and in the second column, subjects from the second period towards which they evolved are listed (To). The

"Words" column indicates the word or expression that contributed to the transition of the topic between the two periods. The Weighted Inclusion Index reflects the frequency with which a word from the initial period appears in the second, adjusted based on keywords. For example, "management information systems" evolved into "sustainable development" with a Weighted Inclusion Index and Inclusion Index equal to 1. The Inclusion Index reflects the elements that the two themes have in common, serving as an overlap measure in the field of information retrieval. When it is equal to 1, it means that the keywords of the first theme are fully contained in the second theme [94]. Another example is "business process", which evolved into "environmental management" with the words "competition" and "green SCM" contributing to this transition. This indicates that "environmental management" directly addresses how business processes are conducted within firms. The Stability Index reflects the consistency in the relationship between research topics, specifically the number of keywords shared between articles published in two consecutive periods. A higher value indicates a tighter and more consistent relationship between the research topics.

**Table 8.** Thematic evolution from 2000–2012 to 2013–2023.

| From (2000–2012) | To (2013–2023) | Words | Weighted Inclusion Index | Inclusion Index | Stability Index |
|---|---|---|---|---|---|
| management information systems | sustainable development | management information systems | 1.00 | 1.00 | 0.01 |
| design | sustainable development | design; design science | 0.75 | 0.33 | 0.01 |
| information management | sustainable development | information management; environmental monitoring | 0.75 | 0.33 | 0.01 |
| sustainable development | sustainable development | sustainable development; environmental sustainability; environmental impact; carbon dioxide; energy utilization; information use; global warming; research agenda | 0.66 | 0.06 | 0.01 |
| business operation | motivation | business operation | 0.50 | 0.50 | 0.05 |
| business operation | sustainable development | sustainable business | 0.50 | 0.50 | 0.01 |
| health care | sustainable development | human-computer interaction; systems analysis | 0.50 | 0.25 | 0.01 |
| business process | environmental management | competition; green SCM | 0.38 | 0.25 | 0.03 |
| ecology | sustainable development | ecology | 0.38 | 0.20 | 0.01 |
| energy efficiency | sustainable development | energy efficiency | 0.38 | 0.33 | 0.01 |

The evolution of topics between the two periods is highly varied, suggesting that the subject is complex and interdisciplinary. It encompasses a mix of research related to business processes, energy consumption, sustainable development, business operations, design, and information management systems. An analysis of these transformations can be used to identify emerging themes and future research directions in the field. An aspect of the table that draws attention, emerging as an important subject for future research, is the evolution of ISs dedicated to the health domain towards sustainable development. Currently, a wide variety of health-related data is being collected. Numerous devices are used to monitor health, and research aimed at identifying the most effective treatments to increase life expectancy is advancing every day. Collecting and processing such a large volume of data has become possible due to technological advancements (AI, IoT, blockchain, etc.), but carrying out these endeavours with minimal negative environmental impact remains a challenge.

The transformation of subjects within the periods under analysis reflects the integration of all concerns into a broader approach, namely, that of sustainable development. Within the context of a holistic approach to humanity's environmental concerns, it is natural for all initiatives to converge towards a broader direction that encompasses the interest in a more sustainable society at all levels and in all aspects. On the other hand, the results of the factorial analysis presented in a previous section reflect concerns in various domains for green IS, such as agriculture, education, automotive, healthcare, banking, etc. They are valued both through the adoption of the latest technologies and by motivating users to adopt a favourable attitude towards environmental protection.

## 4. Discussion

The IS field has significantly evolved in recent decades because of the techno-social context, serving as the foundation for the development of other areas of activity. This study aimed to delineate current trends in green IS development and future research directions through bibliometric analysis. This method has the advantage of allowing for the analysis of a large volume of publications to identify interest in specific areas within a broader domain, pinpointing research gaps and potential opportunities. It was employed to answer the three research questions formulated at the beginning of this study.

Green ISs have emerged as popular research areas because they offer benefits on multiple fronts. The omnipresence of ISs in organizations and communities, coupled with the awareness of their environmental impact, fosters the interest of researchers and industries. ISs constitute a mix of human resources, software, and hardware that collectively and individually influence the economy, society, and the environment. The goal is to use ICT in a minimally invasive manner for the environment while maximizing its potential to mitigate its degradation. Research has highlighted the interdisciplinary nature of this field, addressing the subject from various perspectives such as system design, SCM, energy consumption, carbon footprint, climate change, behaviour, and competition [58–60]. Additionally, concerns have been directed towards diverse areas where ISs are utilized, including aviation, agriculture, banking, education, healthcare, etc. [64–67]. Legislative constraints adopted at the national and international levels by various countries and organizations have acted as both impetus and constraint.

At the organizational level, companies can use green ISs to reduce costs and enhance their market image. At the community level, smart cities employ green ISs to improve the quality of life for citizens by providing more efficient public services and addressing urban challenges by creating innovative solutions [11]. The multitude of interconnected mini-devices that provide rapid access to information and services comes with numerous benefits but also disadvantages such as resource consumption, $CO_2$ emissions, e-waste, and unknown effects on the health of citizens exposed to the invisible connections between devices. As a result, the interest in developing green ISs to improve the performance of existing ISs while simultaneously reducing their environmental impact is a natural direction for the field [76,77,80].

In this research, bibliometric analysis was performed to answer three research questions. The first question was which are the most impactful sources of the literature and who are the most representative authors? To answer this question, we analysed the top ten sources and their impact, reflected by the number of citations. By analysing the most prolific authors and publications, we observed that many publications with significant impact are from the second half of the analysed period, highlighting the increasing relevance of the subject. Additionally, many publications result from the collaborative efforts of research teams rather than individual achievements.

The second research question was what is the status and potential trend of research in green IS? To answer this question, we analysed the frequency and temporal distribution of addressed topics. Throughout the analysed period, subjects such as environmental protection and sustainability, environmental impact, environmental technologies and resource-based, energy efficiency, greenhouse gases, behavioural research, climate change, IoT, and decision theory, all related to ICT, successively constituted the concerns of the authors. Significant interest was devoted to the relationship between green IS and SCM. Additionally, researchers examined the impact of these systems in various domains, along with how business processes should be redesigned to integrate green practices, technologies, and rules. Performance indicators related to environmental impact, as well as the optimization of information flows, were also subjects of analysis.

The third research question was what are the connections between the currently available publications and the evolution of the addressed topics? To answer this question, we analysed the topics collectively addressed within the publications in the dataset. We identified research interests related to system analysis, decision theory and design principles, motivation and business, and global warming from a social perspective and institutional involvement, as well as green IS in developing countries. Additionally, we examined the transformation of various topics by dividing the analysed period into two intervals as follows: 2000–2012 and 2013–2023. We noticed that energy consumption and $CO_2$ emissions are among the main concerns related to green IS. Also, green IS is associated currently with everything smart, such as smart health, smart city, smart environment, etc.

The bibliometric analysis of publications on green IS from the period 2000 to 2023 reveals a research interest oriented towards technical aspects and a fast-paced environment and emphasizes the need for institutional and governmental support to successfully translate academic innovations into societal benefits. The adoption of green IS entails numerous challenges and barriers, encompassing both economic and technical dimensions as well as behavioural aspects. Financial constraints may pose a significant challenge for certain companies, particularly those already grappling with issues during economic crises and the ongoing COVID-19 pandemic, as well as thereafter. The imperative to cultivate a heightened interest in environmental protection can represent another significant challenge, especially considering the limited visibility of the negative impact of ICT on users, despite the omnipresence and often invisibility of devices in our lives. The production and utilization of such devices entail a substantial consumption of resources, some of which are limited and essential for humanity, such as water. For example, according to a study published in 2021 by Mytton, data centres in the USA alone consume 1.7 billion litres per day for both cooling and electricity generation [95]. However, the problem lies in the lack of transparency, as fewer than a third of data centre operators measure water consumption. Fortunately, concerning energy consumption and the carbon footprint, initiatives are much more advanced, with clearer measures and reporting standards, and most of the major ICT equipment and service providers publish detailed environmental reports. We anticipate that initiatives in this field will progress based on trends observed in recent years.

## 5. Conclusions

This study conducts a bibliometric analysis of the literature on the research topics related to green ISs from 2000 to 2023 using Bibliometrix. The analysis focuses on the characteristics and fundamental sources of the literature extracted from periodical publications and specialized volumes. It provides valuable insight into the evolution of the landscape in the field that reveals an active and robust community. We identified key trends, interdisciplinary research, and emerging areas in the field by analysing clusters of research topics and their connections across time. Furthermore, this analysis is useful for identifying research frontiers and providing new perspectives on interdisciplinary hotspots and trends in the field. The volume of primary research published between 2000 and 2023, along with the continuous increase in the number of articles published on this topic, indicates a keen interest in innovation in the field. Issues such as reducing $CO_2$ emissions, increasing energy efficiency, reducing the consumption of non-renewable resources, optimizing business flows, and institutional and individual involvement are among the most researched directions by scholars during the analyzed period. The results highlight the most impactful publications, the most productive authors, and the sources with the most publications in the area. They also shed light on the extent to which publications result from collaboration among diverse author groups. Moreover, the analysis of connections between concepts allows for the delimitation of the most important branches addressed by authors related to green IS and the research lines. The findings elucidate the interconnections among research topics over various periods, unveiling the dynamic evolution and convergence of different areas of study.

The analysis performed allowed us to answer all the research questions formulated at the beginning of this study and presented in Section 1. Recent research also highlights a growing interest in environmental protection, green energy, and sustainable technologies with a focus on digital transformation, smart cities, and digitalization. This indicates that research will continue in the future to create innovative solutions to address the challenge of sustainability in all its dimensions.

Our findings underscore the pivotal role of technological innovations in realizing inclusive environmental objectives through green information systems (ISs). This research makes contributions both theoretically and practically. Drawing upon prior studies and ongoing discourse, researchers can discern the most critical research directions to scrutinize in detail in their future pursuits. Furthermore, this study delineates the most significant trends that companies can exploit for transitioning to green ISs, which can yield various benefits including cost reduction and enhanced market image. Also, this paper could be topical to the end-users of technology and technology developers, increasing their awareness of green aspects. Private and public sector agencies that develop policies and proposals for green ISs can incorporate the main findings in their documentation.

This research is not without limitations. Firstly, the articles in the dataset were extracted only from Scopus. To validate our selection, we replicated the search process on Web of Science. Our findings uncovered 53 documents, 44 of which were duplicates already present in the Scopus dataset. Nonetheless, we maintain our belief that utilizing multiple databases for extracting publications could have offered a more comprehensive overview of the field. Secondly, the names of some authors appear in various forms over time, which may introduce some bias into the analysis. To the extent that these differences were apparent, we attempted to correct them.

The landscape uncovered in this study presented a multidimensional faceted map of green IS that can help society address the theoretical and practical challenges of ongoing environmental degradation. Researchers and practitioners in the field can use the results of this study to improve their understanding of green IS and identify the best sources of information and opportunities for publishing the results obtained from their endeavours.

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