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***"Exploring Sustainable Technological Innovation: A bibliometric analysis"***

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Firma dello studente

Mohammad Aamir

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Mohammad Aamir.

## **Abstract**

This thesis investigates the scholarly landscape of sustainable technology innovation, specifically examining its contribution to improving sustainable business performance, to investigate trends, major contributors, and subject advancements in the discipline, a bibliometric study was performed on papers published between 1991 and 2023, using the Scopus database. The study employs a range of quantitative data analysis techniques, such as descriptive studies of scientific output, co-authorship networks, and citation metrics, to determine the most influential authors, themes, and publications. This includes notable contributions made by authors such as Kumar A., Ghobakhloo M., and Zhang Y., as well as publications such include Sustainability and the Journal of Cleaner Production.

Further analysis revealed that the thematic areas most often examined include “digital transformation,” “technological innovation,” and “sustainable development.” Furthermore, the thesis highlights the increasing significance of digital technologies such as IoT, AI, and blockchain in promoting business sustainability by improving operational efficiency and environmental management. The results emphasize the need of interdisciplinary cooperation to address complexities and expedite the implementation of sustainable innovations in the corporate sector.

The present study provides a thorough overview of the scholarly landscape, identifying both well-established and developing fields of investigation, such as “circular economy” and “digital transformation.” Furthermore, it offers valuable perspectives on the dynamic correlation between technology and sustainability, indicating potential areas for future study that could further enhance our understanding of sustainable business practices.

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## **1. Introduction**

### **1.1. What is Sustainability?**

Sustainability is the management of processes in a way that avoids resource depletion and environmental damage, therefore assuring the capacity of future generations to fulfill their own requirements. The idea is founded upon three fundamental principles: environmental, economic, and social sustainability, also known as the triple bottom line. Environmental sustainability is the management of the ecological footprint by decreasing waste and emissions and preserving biodiversity. The objective of economic sustainability is to facilitate enduring economic expansion while avoiding any adverse effects on the social, environmental, and cultural dimensions of society. Social sustainability is the deliberate effort to enhance the well-being of every individual in society, guaranteeing their access to resources, and upholding principles of fairness and justice (Elkington, 1998).

The concept of sustainability has expanded from a specialized concern to a fundamental component in both policy and corporate strategy. The 2030 Agenda for Sustainable Development, created by the United Nations, delineates 17 Sustainable Development Goals (SDGs) that provide a comprehensive framework for attaining a more sustainable and improved future for all individuals worldwide. The objectives include wide-ranging issues such as poverty, inequality, climate change, environmental degradation, peace, and justice (Transforming Our World: The 2030 Agenda for Sustainable Development | Department of Economic and Social Affairs, 2015). The increasing need to tackle climate change and resource constraint has resulted in a heightened emphasis on sustainable practices in many industries, stimulating innovation and revolutionizing the operational methods of enterprises.

### **1.2. The Evolution and Importance of Sustainability**

The idea of sustainability originated from ancient agricultural techniques, when the balance between raw material used and natural replenishment was crucial for existence. That said, the contemporary concept of sustainability gained greater popularity throughout the latter part of the 20th century. A significant turning point occurred in 1987 when the Brundtland Commission published "Our Common Future," which defined sustainable development as development that satisfies the requirements of the current generation without jeopardizing the capacity of future generations to fulfill their own needs (WCED, 1987). This term established the foundation for

including sustainability into worldwide regulatory frameworks and corporate agendas.

The importance of environmental sustainability has grown significantly because of the evident consequences of climate change, deforestation, and diminishing biodiversity. Businesses are under growing scrutiny for their environmental footprints, including metrics such as greenhouse gas emissions, water use, and the generation of waste. Economic sustainability refers to the capacity of corporate activities to promote long-term economic development while avoiding significant negative impacts on other aspects of society. This pillar focuses on optimizing resource use, fostering innovation, and enhancing resilience in company operations.

Societal sustainability, while often overlooked, is crucial. By addressing concerns like for example equality, diversity, community development, and human rights, it aims to preserve and enhance the well-being of present and future generations. This principle guarantees the equitable distribution of the advantages derived from economic operations and the implementation of business practices that improve the overall well-being of all parties involved (Basiago, 1999).

### **1.3. What is Technological Innovation?**

Technological innovation refers to the creation and implementation of new technologies or the improvements of current technologies to optimize processes, goods, or services. By enhancing efficiency, lowering expenses, and facilitating the emergence of new markets and possibilities, it plays a crucial role in economic development and competitiveness. Technological advancements may be categorized as either incremental, which include minor enhancements, or radical, which include substantial discoveries capable of transforming industries (Schumpeter, 1934).

The domain of technological innovation includes a range of sectors such as information technology, biotechnology, nanotechnology, and renewable energy technologies. This phenomenon is driven by research and development (R&D) endeavors and may be aided by many elements including financial resources, regulatory backing, cooperation among stakeholders, and a favorable innovation environment (Mowery & Rosenberg, 1998). The digital transformation of industries clearly shows the influential effect of technological innovation. Advancements such as big data analytics, artificial intelligence (AI), the Internet of Things (IoT), and blockchain are fundamentally transforming company models and operations.



#### **1.4. The Role of Technological Innovation in Modern Business**

Within the current corporate environment, technological innovation plays a crucial role in driving change and facilitating development. Organizations that leverage the capabilities of technology may optimize their operational effectiveness, elevate customer satisfaction, and generate innovative business models. The advent of the digital revolution has brought upon disruptive technologies that have profoundly transformed the operational landscape of enterprises. Advancements in cloud computing, artificial intelligence, and the Internet of Things have empowered organizations to handle enormous volumes of data, streamline operations, and establish connections across devices in ways that were previously inconceivable (Brynjolfsson & McAfee, 2014).

The Fourth Industrial Revolution, marked by the integration of physical, digital, and biological realms, has accelerated the rate of innovative advancements. The current period is marked by significant progress in areas such as robots, genetic engineering, and quantum computing, that have far-reaching consequences for many sectors. Commercial enterprises are using these technologies to get a competitive advantage, enhance their goods and services, and fulfil the changing demands of their consumers (Schwab, 2016).

Furthermore, technological innovation is essential in tackling worldwide issues such as climate change, healthcare, and food security. Specifically, progress in renewable energy technologies is contributing to a decrease in dependence on fossil fuels, while breakthroughs in biotechnology are facilitating the creation of new medicines and cures for illnesses. Advanced agricultural technology, including precision farming and genetically modified crops, is enhancing food production and sustainability (Miller & Wilsdon, 2001).

#### **1.5. Technological Innovations for Sustainable Business Performance**

achieving sustainable corporate success requires the incorporation of innovative technologies into business operations. Sustainable business performance refers to the capacity of a firm to function in a way that is economically beneficial, ecologically sustainable, and socially accountable. Technological advancements may facilitate this by improving the efficiency of resources, reducing the damaging effects on the environment, and promoting social inclusiveness (Porter & Kramer, 2011).

Technological innovation plays a crucial role in promoting sustainability by accelerating the creation and implementation of clean technology. These technologies strive to mitigate adverse environmental effects by means of energy efficiency, minimization of pollution, effective waste management, and the use of renewable energy sources. Advancements in solar and wind power technology have greatly decreased the cost of renewable energy, enhancing its competitiveness against fossil fuels and providing a valuable contribution to the mitigation of greenhouse gas emissions (Jacobsson & Lauber, 2006).

Furthermore, digital technologies are fundamental in promoting sustainable business practices. Leveraging big data and analytics empowers enterprises to streamline their operations, minimize inefficiencies, and improve their decision-making procedures. Artificial intelligence and machine learning have the potential to improve predictive maintenance, supply chain management, and customer relationship management, resulting in operational efficiency and sustainability in company operations (McAfee & Brynjolfsson, 2012). Blockchain technology provides both transparency and traceability in supply chains, therefore guaranteeing the sustainable and ethical sourcing and production of goods (Saber et al., 2021).

Furthermore, technological advancements might facilitate the circular economy, a paradigm that prioritizes the reutilization, recycling, and rejuvenation of resources and products to prolong their lifespan and minimize environmental waste. The monitoring and optimization of resource usage are made possible by technologies such as IoT and smart manufacturing, which in turn facilitate the transition towards a circular economy (Geissdoerfer et al., 2017). The circular economy is in fundamental opposition to the conventional linear economy, which adheres to a "take-make-dispose" paradigm. The circular economy seeks to maximize the value created by goods and resources by extending their usage, hence optimizing waste management and mitigating environmental effect (Ellen MacArthur Foundation, 2013).

#### **1.6. Case Studies of Technological Innovations in Sustainable Business Practices**

Several case studies highlight how companies have effectively used technical advancements to achieve sustainability. As an example, Interface Inc., a worldwide producer of modular carpet tiles, has been in the forefront of implementing sustainable operations via its Mission Zero

program. The objective of this effort is to eradicate all adverse environmental effects caused by the firm by the year 2020. Interface has used technologies such as biomimicry to create goods that imitate the processes of nature, therefore minimizing waste and energy usage. Furthermore, the firm incorporates recyclable materials and renewable energy into its production operations, therefore substantially reducing its carbon emissions (Anderson, 1998).

Tesla, Inc. is another example that has deeply transformed the automotive sector with its electric cars and environmentally friendly energy solutions. The battery technology, energy storage, and electric vehicle manufacturing advancements made by Tesla have established unprecedented benchmarks for sustainability within the automobile industry. Tesla's Gigafactories, which manufacture large-scale batteries and energy storage systems, generate electricity from renewable sources, hence strengthening the company's dedication to sustainability (Stringham et al., 2015).

Across its supply chain, Walmart has successfully integrated a range of technical advancements to improve sustainability in the retail industry. The objective of Walmart's Project Gigaton is to achieve a reduction of one billion metric tons in emissions throughout its supply chain by the year 2030. Big data analytics and artificial intelligence are used by the organization to enhance logistics, increase energy efficiency, and minimize waste. In addition, Walmart engages in partnerships with suppliers to implement sustainable measures, including the reduction of packaging and the responsible procurement of resources (Plambeck & Denend, 2008).

### **1.7. The Future of Technological Innovations for Sustainable Business**

The prospects for technological innovation in achieving sustainable company performance are very encouraging, since several new trends are expected to propel further progress. Incorporating artificial intelligence and machine learning into sustainability initiatives is anticipated to augment predictive capacities, maximize resource use, and boost decision-making accuracy. Artificial intelligence has the capability to examine complex datasets to detect patterns and get valuable information that may be used to promote sustainable practices. This includes enhancing energy efficiency in buildings and forecasting equipment malfunctions in industrial environments (Russell & Norvig, 2016).

The use of blockchain technology, most often associated with cryptocurrency, is increasingly being recognized to augment transparency and traceability inside supply chains. Through its decentralized and unchangeable transaction record, blockchain technology can guarantee the ethical and sustainable sourcing and production of goods. In sectors like food and pharmaceuticals, where traceability is essential for guaranteeing product safety and integrity, this technique is very valuable (Kouhizadeh et al., 2021).

A further domain with substantial promise for promoting sustainability is the Internet of Things. Industrial Internet of Things devices have the capability to actively monitor and regulate energy use, water consumption, and waste production in real-time. This allows enterprises to promptly address inefficiencies and minimize their environmental footprint. Smart grids, linked buildings, and precision agriculture highlight the use of the Internet of Things to advance sustainable practices (Ashton, 2009).

The ongoing progress in renewable energy technology remains a crucial domain of innovation. The increasing efficiency and affordability of solar and wind power technologies have made them feasible substitutes for fossil fuels. Energy storage technologies, such as sophisticated batteries and pumped hydro storage, are effectively tackling the problem of intermittent availability linked to renewable energy sources. For the transition to a low-carbon energy system and the attainment of global climate objectives, these technologies are essential (Gielen et al., 2019).

The circular economy is gaining significant traction as a conceptual framework for attaining sustainability. Enterprises are progressively embracing circular methodologies such as designing products for easy dismantling, recovering materials, and implementing closed-loop supply networks. Technologies that facilitate these behaviors, like sophisticated recycling techniques and digital platforms for managing the whole lifespan of products, are crucial for enabling the circular economy. Organizations may generate value from trash and minimize their environmental impact by reconsidering product design and material use (Lacy & Rutqvist, 2015).

### **1.8. Challenges and Opportunities in Technological Innovations for Sustainability**

While technological advancements have significant potential for promoting sustainability, they

also pose challenges that need to be recognized and resolved. An inherent challenge is the significant financial investment required to develop and execute new methods. For firms, particularly small and medium-sized enterprises (SMEs), the substantial upfront costs could act as a barrier since they may lack the required resources to invest in advanced technology. Financial incentives, subsidies, and collaborations between the public and private sectors might help in decreasing these costs and encouraging broader use of sustainable technologies (Popp, 2010).

One other challenge is the need for skilled labor to implement and maintain advancing technologies. The fast pace of technical progress necessitates a professional who has expertise in the latest technologies and can adapt to new tools and processes. This necessitates continuous education and training programs to provide staff with the necessary competency. The creation and execution of effective training programs needs active collaboration among industry, academia, and government (Autor, 2015).

Safeguarding data and maintaining confidentiality are significant concerns, particularly considering the increasing use of digital technologies. It is essential for businesses to ensure the protection of data collected via IoT devices, blockchain systems, and other digital infrastructure from cyber adversaries. Effective protection of sensitive information and maintenance of stakeholder trust require the establishment of robust cybersecurity protocols and legal structures (Gordon & Loeb, 2002).

Notwithstanding the presence of these issues, the potential provided by technology progress for sustainability is vast. Organizations that optimize the use of sustainable technology may gain a competitive advantage by reducing costs, increasing efficiency, and strengthening their brand reputation. The growing consumer demand for environmentally friendly products and services presents a significant market opportunity for companies that prioritize sustainability (Nidumolu et al., 2009).

Furthermore, technological progress also offers opportunities for collaboration and the interchange of technical knowledge. Open innovation platforms and ecosystems enable collaboration among firms, academia, and governments to accelerate the development and spread

of sustainable technologies. By harnessing collective knowledge and aligning resources, stakeholders may accelerate the pace of innovation and achieve a greater level of impact (Chesbrough, 2003).

## **2. Our Research**

This thesis employs a comprehensive bibliometric analysis to explore the research landscape of sustainable technological innovation for sustainable business performance. Our objective is to identify key trends, influential contributors, and thematic developments within this multidisciplinary field. The methodology and findings of our analysis are outlined as follows:

### **2.1. Methodology Used**

We began our research by conducting an extensive literature review to firmly build a theoretical foundation and ascertain the scope of our research. Implementing the PRISMA technique, we performed a thorough assessment of the current literature, ensuring a rigorous and consistent strategy for collecting and interpreting data. This work used the Bibliometrix package in R, an advanced tool for doing bibliometric research, to gather and analyze data from academic papers included in the Scopus database. The search query was explicitly designed to include papers related to digital innovation, technological innovation, and sustainable business performance, published from 1991 to 2023.

### **2.2. Data Collection**

Our preliminary search resulted in a significant collection of 1,510 entries obtained from 678 distinct scholarly publications, books, and conference papers. This collection of papers covers more than thirty years of study, illustrating the changing interest and investigation of how technical advancements might promote sustainable business practices. The dataset was refined to include only English-language academic articles classified under the fields of Business Management, Accounting, Economics, Econometrics, and Finance.

### **2.3. Bibliometric Analysis**

A range of bibliometric studies were conducted to map the research landscape, including:

**Descriptive Analysis:** This includes a thorough investigation of the yearly scientific output, which revealed a notable surge in publications starting from 2017. Concurrent with the worldwide focus on sustainability and technological transformation, there has been a notable increase in research effort.

**Authorship and Collaboration Networks:** To determine the most productive authors and joint research endeavors, we conducted an analysis of the co-authorship networks. This study highlighted the significant contributions made by Kumar A., Ghobakhloo M., and Zhang Y., and showcased a considerable degree of international cooperation in this domain.

**Citation Analysis:** The most often referenced publications and prominent writers were determined by citation analysis, with Vial G. (2019) and Teece D.J. (1997) appearing as crucial references. The present study highlights the fundamental ideas and developing patterns that are propelling research in the fields of technological innovation and sustainability.

**Keyword Analysis:** Through the examination of mostly used terms, we have found major themes and areas of study, including "digital transformation," "technological innovation," and "sustainable development." This analysis offered valuable perspectives on the main areas of concentration and currently ongoing discussions within the discipline.

**Thematic Analysis:** Within the framework of conceptual structure mapping, we used term co-occurrence networks and thematic maps to visually represent the interconnections among various study subjects. Upon study, mature themes such as "innovation" and "sustainability" were identified, along with emergent ones like "digitization" and "circular economy."

**Source Analysis:** The most relevant journals and sources were found, with Sustainability (Switzerland) and the Journal of Cleaner Production emerging as the top performers in terms of publication volume. The application of Bradford's Law determined the classification of journals into core and peripheral sources, therefore emphasizing the clustering of significant material within a limited number of important publications.

#### **2.4. Research objectives**

The bibliometric analysis in our study offers a comprehensive summary of the research environment, emphasizing noteworthy patterns and prominent authors. The data suggest an increasing inclination towards combining technology breakthroughs with sustainable business strategies, propelled by progress in technologies and a worldwide effort towards sustainability. The study further emphasizes the requirement of multidisciplinary cooperation and the need for a unified research program to tackle the complex issues and possibilities in this domain.

The present thesis aims to expand the comprehension of how technological breakthroughs might improve sustainable company performance by conducting a comprehensive mapping of the research environment. The findings obtained from this study may guide future research endeavors, policy formulation, and practical implementations, eventually facilitating the shift towards more sustainable and resilient corporate practices.



### 3. Research Background

#### 3.1. Methodology

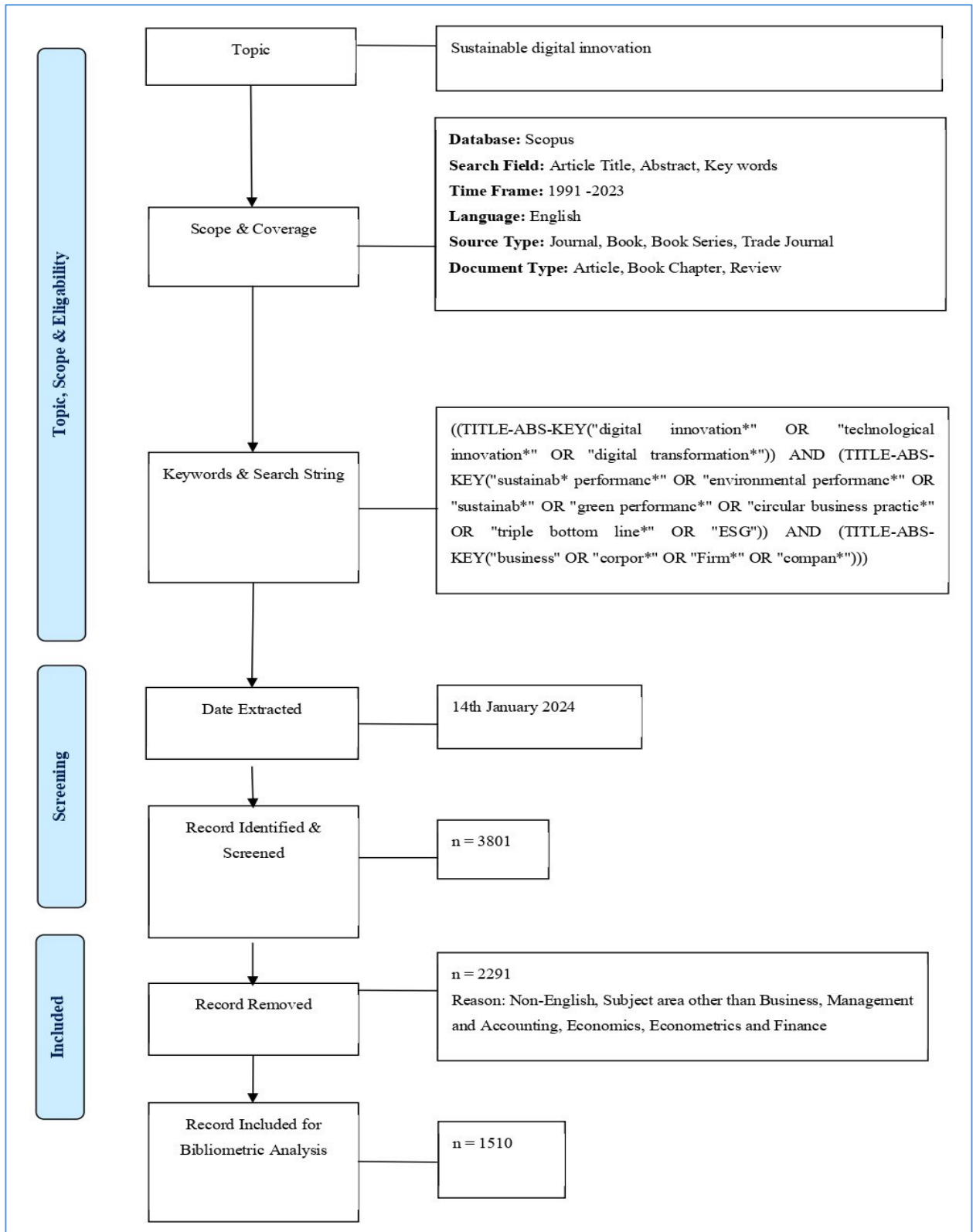


Figure 1, PRISMA Framework

For this analysis, we used Bibliometrix which is an R-based software package that allows users to perform bibliometric analysis on scientific literature. It follows a recommended workflow for bibliometric studies that involves several steps employing diverse analyses and mapping software tools. Bibliometrix automates this workflow into an organized data flow within the R programming environment (Aria & Cuccurullo, 2017).

It can be used to analyze citation networks, co-authorship networks, and keyword co-occurrence networks, among other things. The first step is data collection. To conduct the analysis, academic papers were retrieved from the Scopus database on 14th of January 2024, using the following comprehensive search query with relevant keywords:

**((TITLE-ABS-KEY("digital innovation\*" OR "technological innovation\*" OR "digital transformation\*")) AND (TITLE-ABS-KEY("sustainab\* performanc\*" OR "environmental performanc\*" OR "sustainab\*" OR "green performanc\*" OR "circular business practic\*" OR "triple bottom line\*" OR "ESG"))) AND (TITLE-ABS-KEY("business" OR "corpor\*" OR "Firm\*" OR "compan\*"))))**

This query focused on papers with terms related to digital innovation ("digital innovation\*", "technological innovation\*", "digital transformation\*") and sustainable business performance (("sustainab\* performanc\*", "environmental performanc\*", "sustainab\*", "green performanc\*", "circular business practic\*", "triple bottom line\*", "ESG") with specific to business organizations ("business", "corpor\*", "Firm\*", "compan\*") in the title, abstract, or keywords.

Results were limited to English language, papers categorized under the Business, Management and Accounting, Economics, Econometrics and Finance subject area in Scopus and year from 1991 to 2023.

Now that the data is collected, the next step is conducting analyses to understand patterns in the publications. Bibliometrix has functions to perform descriptive analyses of trends over time, contributors, sources, and other variables. It can create networks based on citation, bibliographic coupling, co-citation, or collaboration analysis. These networks are normalized using similarity

measures to identify connections between publications, authors, references, etc. Conceptual structure mapping uses multiple correspondence analysis and clustering techniques to generate a term co-occurrence network (Aria & Cuccurullo, 2017).

The next step involves creating representations by graphs and maps. Scholars can plot trends, citations, and collaborations. Additionally, you have the option to visualize networks using layouts and parameters. Another useful tool is generating structure maps that illustrate the connections between research topics and themes.

Now that the data collection is done and 803 papers have been extracted from Scopus, let's delve into the analysis.

## 4. Bibliometric Analysis

### 4.1. Main Information

The primary data in this collection covers articles from 1991 to 2023, which together represents more than three decades of intellectual study. The significant duration of this time interval highlights the enduring and developing investigation of the influence of technical advancements on the sustainable functioning of corporate entities.

Description	Results
<i>MAIN INFORMATION ABOUT DATA</i>	
<i>Timespan</i>	<b>1991:2023</b>
<i>Sources (Journals, Books, etc)</i>	<b>678</b>
<i>Documents</i>	<b>1510</b>
<i>Annual Growth Rate %</i>	<b>21.55</b>
<i>Document Average Age</i>	<b>4.04</b>
<i>Average citations per doc</i>	<b>20.6</b>
<i>References</i>	<b>88997</b>
<i>DOCUMENT CONTENTS</i>	
<i>Keywords Plus (ID)</i>	<b>2821</b>
<i>Author's Keywords (DE)</i>	<b>4193</b>
<i>AUTHORS</i>	
<i>Authors</i>	<b>4004</b>
<i>Authors of single-authored docs</i>	<b>225</b>
<i>AUTHORS COLLABORATION</i>	
<i>Single-authored docs</i>	<b>237</b>
<i>Co-Authors per Doc</i>	<b>3.06</b>
<i>International co-authorships %</i>	<b>26.56</b>
<i>DOCUMENT TYPES</i>	
<i>article</i>	<b>1185</b>
<i>book chapter</i>	<b>259</b>
<i>review</i>	<b>66</b>

Figure 2, Main Information TABLE, Bibliometrix Tool

The analysis of the dataset shows the collection of 1,510 written materials obtained from a remarkable variety of 678 sources. The extensive compilation of research papers, books, book series, and trade magazines demonstrates the academics' keen interest in investigating the influence of technological advancements on the sustainability performance of corporate organizations. Significantly, the number of these publications has consistently grown at an annual rate of 21.55%, aligning with the growing worldwide emphasis on enhancing the

sustainable performance of business organizations by implementing innovative technologies in various business sectors.

Upon scrutiny of the papers in this collection, the mean age is estimated to be about 4.04 years. Significantly, most of these works are of recent origin, indicating a heightened emphasis on sustainability and technological advancement in recent times. Given that the dataset spans 33 years, an average age of just over four years suggests that the study is quite youthful and active, demonstrating both ongoing and recent progress in the area.

The average number of citations per document is around 20.6, indicating the significance and influence of this study field. An effective measure to evaluate the average influence of journals or authors is the calculation of average citations, which is obtained by dividing the total number of citations by the total number of articles (Anne-Will Harzing, 2010). This might serve as an indicator of the significance and impact of the study throughout the scholarly community.

There are a total of 88,997 references distributed across the written materials. These citations exhibit a complex network of interrelated information, illustrating a vast collection of literature that scholars rely on to construct their study.

An analysis of the keywords used reveals a total of 2,821 Keywords Plus phrases and 4,193 author's keywords. Keywords Plus are produced by an automated computer algorithm and indicate words or phrases that commonly occur in the titles of references in an article but may not be included in the article title or as author keywords (Eugene Garfield & Irving H. Sher, 1993). Author Keywords are the specific phrases that writers consider to be the most representative of the content of their published work (Zhang et al., 2016). Both categories of keywords are essential for indexing objectives and accurately reflecting the subjects addressed in the papers. They facilitate the identification of research trends and topic emphasis within the research domain.

The dataset comprises contributions from a grand total of 4,004 writers, out of whom 225 are exclusive authors of single-authored papers. These findings indicate a substantial degree of cooperation among scholars in this area. The mean number of co-authors per document is 3.06,

suggesting a very elevated degree of collaborative research, a characteristic that is prevalent in scientific investigations and underscores the interdisciplinary character of this study field.

Furthermore, 26.56% of the papers show instances of international partnerships among authors. Such a high proportion signifies a robust degree of international collaboration and underscores the worldwide attention and endeavors in researching the influence of technological advancements on sustainable business performance.

The bibliometric analysis reveals that journal articles are the predominant document type, including 1,185 publications. Next in line are book chapters (259) and review articles (66). The abundance of journal papers indicates a persistent and dynamic research discourse in academic and professional environments, where original discoveries and continuing research are often published. Book chapters and review articles provide more detailed analyses of topics, making a noteworthy contribution to the widespread distribution of complete information.

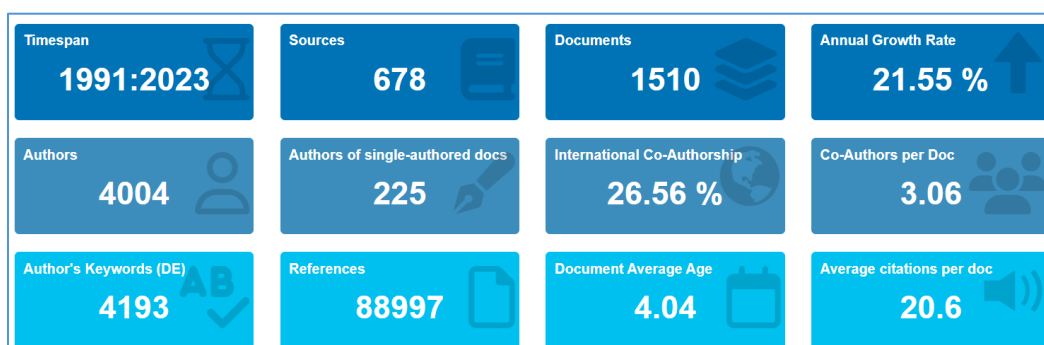


Figure 3, Main Information, Bibliometrix Tool

Overall, the primary data shown above, derived from the bibliometric analysis, offers a comprehensive summary of the vast body of research on digital or technological advances relevant to sustainable business performance. Indicating an expanding and dynamic area with substantial international cooperation and a high degree of academic interest, the dataset covers a period of more than three decades. The modern emphasis on sustainability and digitalization is apparent from the very young average age of papers and the significant citation effect, highlighting the pertinence and significance of this study field in current academic and professional discourse. The dataset's broad range of sources and collaborative efforts emphasize the interdisciplinary character of the area, which is constantly developing alongside new emerging technological breakthroughs and environmental issues.

## **4.2. Annual Scientific Production**

The analysis of the yearly scientific output from 1991 to 2023 reveals the advancement of research in the field of how digital or technological innovation affects the sustainable operation of business organizations. An analysis of the data obtained from Biblioshiny in the Bibliometrix program offers a thorough perspective on the historical development of academic interest and productivity in this subject.

Notably, the early years, namely the 1990s and early 2000s, saw little academic involvement with this subject. Throughout this age, marked by restricted internet access and emerging technical progress, books remained scarce. In fact, our search did not find any published articles on this topic before 1991, highlighting the freshness of this discipline during that period. The scarcity of publications in these first years may be attributed to the early stage of technology as well as the concept of sustainability, and the limited acceptance in contemporary commercial operations. Thus far, scholars have not thoroughly investigated the possible connections between technological innovation and sustainable business performance.

From the early 2010s forward, there was a noticeable rise in academic interest, however with a little growth in the number of publications. Notwithstanding the introduction of fourth-generation internet technologies and the early embrace of digitalization by enterprises, research progress remained stagnant. The limited number of studies conducted during this time span may be attributed to the early stages of incorporating digital innovation into company operations, along with a scarcity of empirical data to support assertions about its influence on sustainability. The incremental increase in publications throughout these years is indicative of the prudent strategy adopted by both enterprises and scholars, as they started to comprehend and explore new digital technologies and their possible effects on sustainability.

Nevertheless, the trajectory changed significantly starting from 2017, indicating a fundamental change in both the emphasis and resulting outcomes of study. The significant increase of publications, from 31 in 2017 to 181 in 2021, highlights the increasing acknowledgment among firms of the need to use technical progress to enhance sustainable performance. This era signifies the start of a substantial transformation, in which digital innovation first emerged as a pivotal catalyst for attaining sustainable business practices. The accumulation of substantial data by

researchers facilitated the development of more rigorous evaluations on the relationship between technological or digital innovation and sustainable business practices.

The period after 2021 saw a rapid and significant increase in academic contributions, characterized by a remarkable surge in paper publications, which reached a total of 515 by 2023. This spike is associated with the worldwide disruption caused by the COVID-19 pandemic, which acted as a stimulus for rapid digital transformation in many sectors. The epidemic compelled enterprises to swiftly embrace digital technology, resulting in an unparalleled dependence on applications such as remote communication platforms and inventive solutions across several industries. The widespread use of remote communication technologies including Zoom and innovative telemedicine solutions, such those created by Telus in Canada, underlined the important influence of technological developments in efficiently handling crises and so promoting resilience (Industry Reports on Telemedicine Solutions, 2023).

Moreover, breakthrough technologies include big data analytics, cloud computing, Internet of Things (IoT) devices, and Industry 4.0 define the contemporary surroundings. Industry 4.0 Reports, 2023 suggest that these technologies might completely change ideas of sustainability and rethink business strategies. The need for improved efficiency, resilience, and sustainability drives the fast incorporation of these technologies into business processes. The junction of sustainability demands with technological advancement defines this new age of research and practice. Companies now must be flexible and creative if they are to thrive in a connected and ever more complex global scene.

The annual scientific production figures reflect this changing conversation. Emerging from its early stages of low research output to the current time of amazing growth, the trajectory emphasizes the great capability of digital innovation to affect the sustainability objectives of companies worldwide. Inspired by both pragmatic needs and theoretical development, the fast rise in paper production beginning from 2017 points to a notable degree of research effort and interest. The pattern shows how digital technology moves from periphery to central concerns in modern discussions on environmentally friendly company policies.



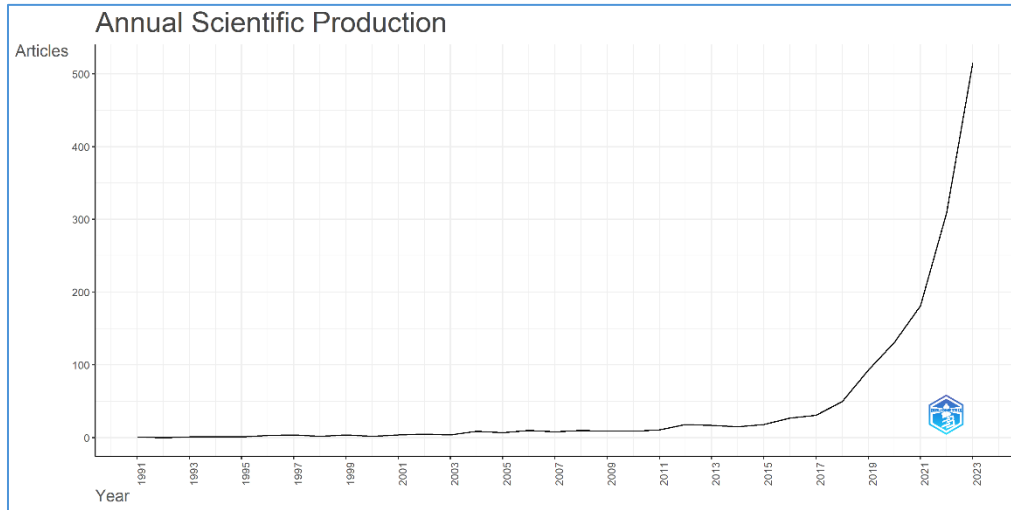


Figure 5, Annual scientific production, Bibliometrix Tool

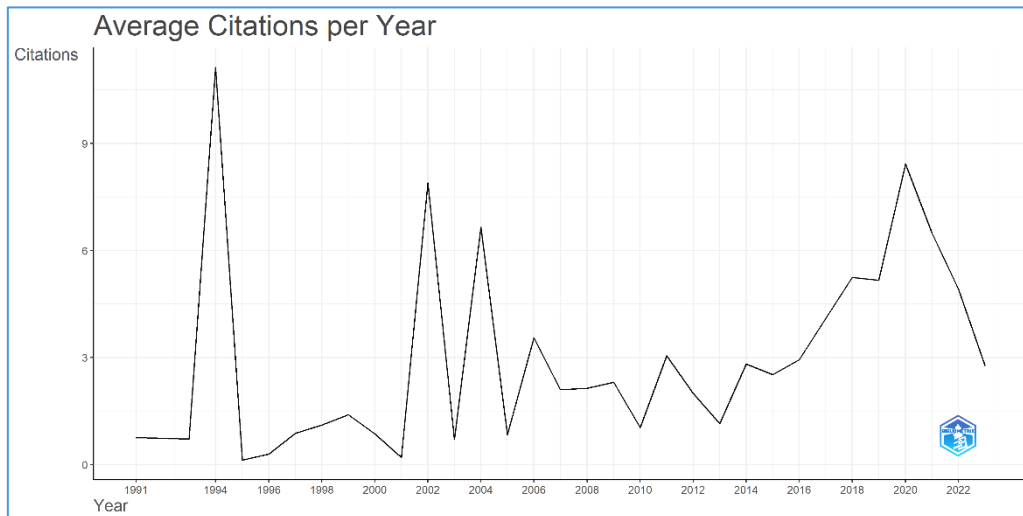


Figure 4, Average citations per year, Bibliometrix Tool

In conclusion, analysis of annual scientific output reveals a vibrant and fast-growing subject. Originally marked by little participation, the early years experienced a considerable increase in academic output particularly beginning in 2017. The above-described change emphasizes the growing importance of digital innovation in achieving sustained organizational success. Driven by global crises and fast technology development, the present spike of publications emphasizes the relevance and future directions of the issue. Companies trying to increase their sustainability and agility in response to present and future challenges will depend on effective understanding and strategic use of digital technology. Thus, the annual scientific output data not only records past progress but also shows a great future for research at the junction of digital innovation and



**References (CR):** Showed on the left side of the graph, the references field lists the most often referenced works in the literature. Important references include pieces by Osterwalder A. (2010), Teece D.J. (1997), and Vial G. (2019). Most of the present studies on digital transformation and sustainable business performance are built on these sources.

Particularly impactful with his thorough analysis of digital change is Vial G. (2019). This work is a pillar for anybody investigating digital innovation as it offers a comprehensive study of how digital technology influence corporate strategy and operations. Another classic source is Teece D.J. (1997), who is well-known for his research on dynamic capabilities—qualities firms need to be able to adjust and flourish among technological developments. By stressing the need of customizing business models to properly use digital developments, Osterwalder A. (2010) presents a generally accepted paradigm for business model innovation.

Other noteworthy sources include Chesbrough H.W. (2003), who talks about open innovation and the need to benefit from technology; Elmassah S. and Mohieldin M. (2019), who concentrate on digital transformation and sustainable development goals (SDGs). The cited sources are crucial as they provide both theoretical and practical perspectives on the use of digital technology to attain sustainable business achievement.

**Keywords (DE):** Showed on the right side of the graphic, the keywords field highlights the primary subjects and issues addressed in the study. Keywords of note include “digital transformation,” “technological innovation,” “sustainable development,” and “business model innovation.” These keywords capture the main areas of concentration and represent changing research trends.

The most often recurring term is “digital transformation,” which emphasizes the fundamental subject of how digital technologies are changing corporate operations. Linked to many writers and references, this term clearly has great significance and value. Prominent also are “technological innovation” and “sustainable development,” which draw attention to the junction of sustainability and technology in the scholarly debate.

Keywords such as “dynamic capabilities,” “circular economy,” and “Industry 4.0” highlight the many facets of the study even further. Often connected with Teece D.J. (1997), “dynamic capabilities” are the capacity of companies to combine, develop, and reorganize internal and external skills to handle fast changing surroundings. Emphasizing the sustainable use of resources—a key component of reaching long-term sustainability targets—the circular economy Further tying the issues of innovation and sustainability, “Industry 4.0” reflects the continuous change in manufacturing and industrial processes brought about by digital technology

**Interplay and Insights:** The three-field layout deftly shows the intricate interactions among authors, references, and keywords. Key persons spanning important references and developing ideas include authors like Kumar A. and Ghobakhloo M. Often recognized, their work shows their impact on the area by exploring important subjects such digital transformation and sustainable development.

The references linked to these writers and keywords draw attention to the fundamental ideas guiding the study as well as developing trends Crucially important publications by Vial G. (2019) and Teece D.J. (1997) provide fundamental ideas and frameworks that support much of the present debate on digital innovation and sustainability. The recurrent keywords show areas where digital technologies are being used to improve sustainability performance, therefore reflecting the topic emphasis of the study.

This study emphasizes how dynamically research on digital or technical innovations for sustainable corporate performance is changing. Driven by the need to reach sustainability targets and respond to technological changes, the dynamic and fast expanding sector of digital technology integration into corporate processes is for both academics and practitioners, the three-field plot offers a thorough picture of the main contributors, basic references, and important themes, thereby guiding both sides.

To sum up, the three-field plot analysis exposes the complex interactions among important topics in the study of digital or technological breakthroughs for sustainable business performance, basic references, and prolific writers. While sources like Vial G. (2019) and Teece D.J. (1997) provide necessary theoretical foundations, authors like Kumar A. and Ghobakhloo M. are vital in

furthering the topic. The recurrent terms represent the changing debate and show the main areas of attention, therefore reflecting the continuous developments. This visualization emphasizes the need for digital transformation and technical innovation in promoting sustainable business practices, therefore providing a road map for further studies and useful applications.

#### 4.4. Most Relevant Sources

Analyzing source relevance will help one to have a complete awareness of the landscape of yearly scientific paper publishing related to the interaction between digital or technology innovation and the sustainable performance of corporate organizations. This helps us to find the key publications and journals in this field of research.

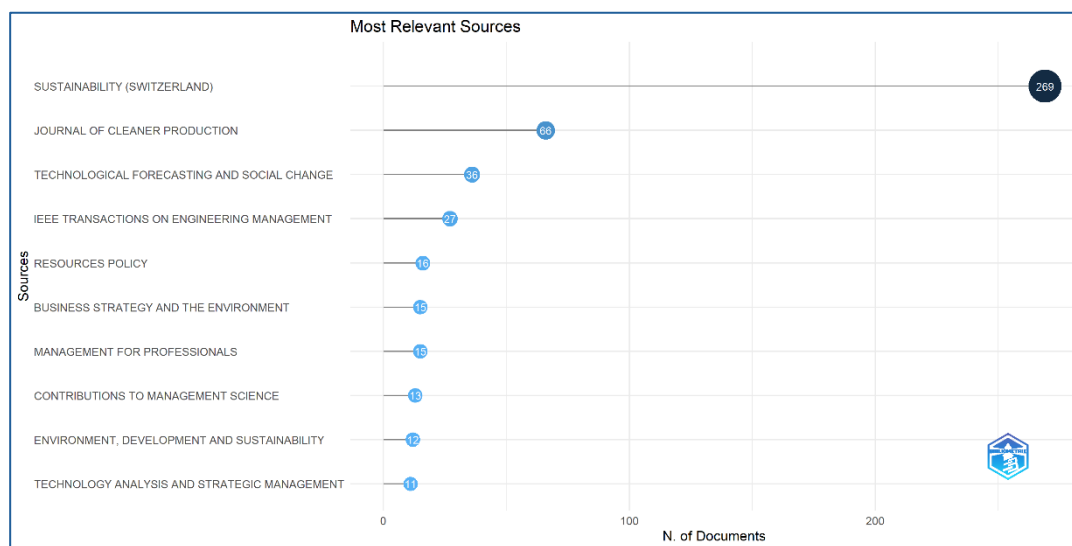


Figure 7, Most relevant sources, Bibliometrix Tool

Our results show that the data covers books and papers from many different sources, including journals, and other forums. With 269 entries, **Sustainability (Switzerland)** stands out as the leading journal in this area. Sustainability, an open-access peer-reviewed journal by MDPI, ranks 101st out of 779 significant publications and thoroughly addresses all facets of sustainability research (Scopus, 2024). The significant publishing volume in Sustainability emphasizes the need of digital or technological innovation in promoting sustainability within companies.

Following closely is the **Journal of Cleaner Production** with 66 publications. This

international, transdisciplinary journal focuses on Cleaner Production, Environmental, and Sustainability research and practice (ScienceDirect, 2024). Its prominence as the second most influential journal within our dataset underscores the broad impact of our research topic across various business sectors and societal domains.

Ranked third in relevance with 36 articles is **Technological Forecasting and Social Change**. Emphasizing the interaction of social, environmental, and technical elements, this journal provides a main platform for the methodology and practice of technology forecasting and future studies (ScienceDirect, 2024). This emphasizes the interdisciplinary character of the link between sustainable performance and innovation in technology.

Other important publications are **IEEE Transactions on Engineering Management** (27), **Resources Policy** (16), **Business Strategy and the Environment** (15), **Management for Professionals** (15), **Contributions to Management Science** (13), **Environment, Development and Sustainability** (12), and **Technology Analysis and Strategic Management** (11). From management to manufacturing, these papers highlight the many aspects of using digital or technological advances across several corporate sectors in order to improve sustainable performance. Particularly, the sixteen papers in Resources Policy highlight the vital part government policies play in enabling the use of digital advances to meet goals of sustainability.

The popularity of publications such as **Sustainability (Switzerland)** and the **Journal of Cleaner Production** shows a significant emphasis on sustainability research, therefore reflecting the increasing relevance of including digital technology to support sustainable business practices. These publications provide a forum for sharing innovative ideas on how modern technologies could propel sustainability in many spheres.

When we look at the significance of these sources, we can find that the study is rather multidisciplinary and involves contributions from disciplines like engineering, management, environmental science, and social studies. The variety of sources emphasizes the many aspects of the study on digital or technical breakthroughs for sustainable corporate performance. It also reflects the general enthusiasm and involvement of many academic and professional groups in investigating how digital technology may support sustainable development.

The data also reveals a trend towards increased collaboration and cross-disciplinary research. Publications bridging the gap between technology and management, including IEEE Transactions on Engineering Management and Technological Forecasting and Social Change, provide insights on how digital advances could be deliberately controlled to reach sustainability objectives. Combining technical, managerial, and environmental points of view, this movement emphasizes the need for a holistic approach for research.

Furthermore, the great volume of articles in journals such as Business Strategy and the Environment, Development and Sustainability indicates the strategic relevance of matching corporate practices with environmental sustainability. These publications show the important part strategic planning plays in reaching long-term sustainability objectives by frequently including studies on green technology, sustainable business models, and regulations supporting sustainable development.

Overall, the great volume of papers in prestigious journals emphasizes the need for digital or technological innovations as a fundamental field of research. These publications not only help to advance knowledge in the subject but also underline the need to include innovation for environmentally friendly corporate strategies. Examining the most relevant materials shows a lively and colorful research landscape marked by multidisciplinary cooperation and a strong sustainability concentration. The many varieties of publications releasing studies on this issue shows the general awareness of the possibility of digital technology to propel environmentally friendly corporate performance. As companies and academics give sustainability top priority in face of global issues such resource constraints and climate change, this trend is probably going to persist.

#### **4.5. Bradford's Law**

For scholars, knowing the distribution of literature within a certain area is essential, and Bradford's Law—a model defining the distribution of papers among publications—often helps them to grasp this. Originally proposed by Samuel C. Bradford in 1934, this law uses article concentration to distinguish core and peripheral journals, therefore supporting bibliometrics and

information science.

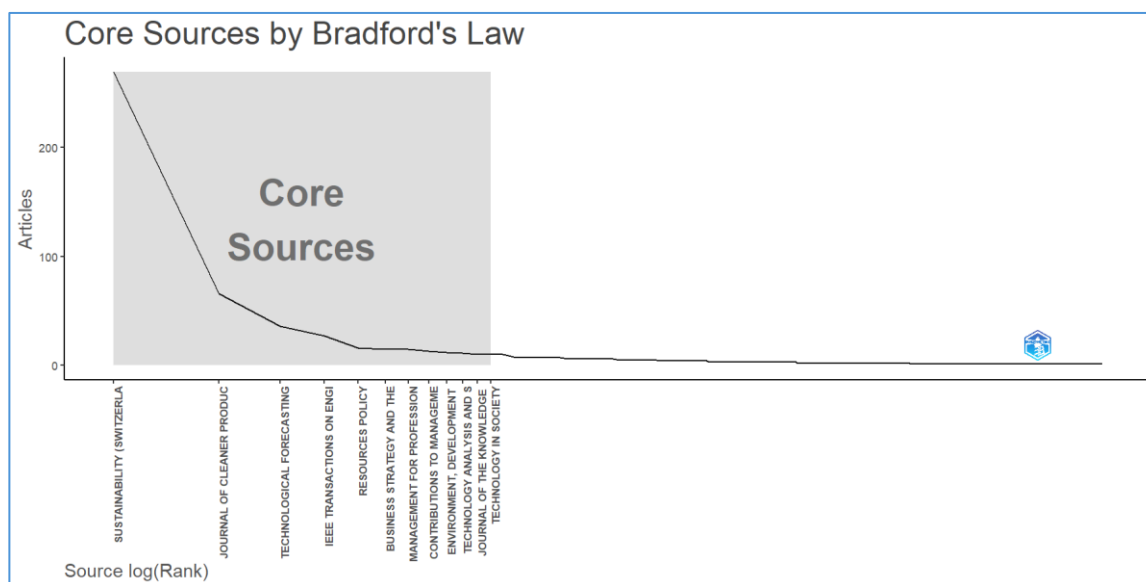


Figure 8, Core Sources by Bradford's Law, Bibliometrix Tool

Bradford's Law divides scientific publications into three zones with equal article count. From one zone to another, the average number of articles per journal lowers as the count of journals rises. As a result, although peripheral journals include less relevant material, a cluster of core journals has a good number of papers on a certain subject.

Using Bradford's Law as our study subject, we get the usual distribution pattern. A small number of publications, reflecting the core, have a noteworthy number of pieces investigating the junction of technological innovation and sustainable business performance.

According to the study, **Zone 1** consists of the most important publications in this discipline. Among these are **Sustainability (Switzerland), Journal of Cleaner Production, Technological Forecasting and Social Change, IEEE Transactions on Engineering Management, Resources Policy, Business Strategy and the Environment, Management for Professionals, Contributions to Management Science, Environment, Development and Sustainability, Technology Analysis and Strategic Management, Journal of the Knowledge Economy.** Following Bradford's Law, these publications together provide 500 articles, over one-third of the total 1510 papers examined.

With 269 papers, **Sustainability (Switzerland)** is the most productive publication in **Zone 1** and



emphasizes its critical part in spreading research on digital or technological innovation for sustainable company performance. Published by MDPI, this journal is a main source for academics in sustainability as it covers a broad spectrum of relevant topics (Scopus, 2024).

Another important journal in *Zone 1* is 66-article **The journal of Cleaner Production**. Emphasizing the need of creative ideas in reaching sustainability targets, this worldwide journal covers cleaner production, environmental, and sustainability research and practice (ScienceDirect, 2024).

Third in *Zone 1* with 36 entries is **Technological Forecasting and Social Change**. Emphasizing the interaction of social, environmental, and technical elements, this journal provides a main venue for the approach and practice of technology forecasting and future studies (ScienceDirect, 2024). This emphasizes the interdisciplinary character of the link between sustainable performance and innovations in technology.

**IEEE Transactions on Engineering Management** (27 articles), **Resources Policy** (16 articles), **Business Strategy and the Environment** (15 articles), **Management for Professionals** (15 articles), **Contributions to Management Science** (13 articles), **Environment, Development and Sustainability** (12 articles), and **Technology Analysis and Strategic Management** (11 articles). From management to manufacturing, these publications highlight the many aspects of using digital or technical advancements across several corporate sectors to improve sustainable performance.

Turning now to *Zone 2* and then *Zone 3*, the number of articles per journal falls even as the number of journals grows. This is consistent with Bradford's Law's theory, which projects each zone to accommodate around one-third of all articles. Though both *Zone 2* and *Zone 3* have more journals, each one publishes less about technological innovation and sustainable business performance.

Among the journals available in *Zone 2* and *Zone 3* are **Technology in Society**, **Technovation**, **Sustainable Development**, **Energy Research and Social Science**, **European Journal of Innovation Management**, and **IEEE Engineering Management Review**. Though they publish

less pieces individually, these journals together add to the body of knowledge in this topic by providing other points of view and specialized insights not as common in the main publications.

Bradford's Law's application to this dataset shows its value in locating fundamental sources of literature within a study field. Prioritizing *Zone 1* publications for academics and libraries helps them to obtain a significant amount of material on technological innovation and sustainable business performance without searching through many peripheral journals. For those doing systematic reviews or targeted research, when thoroughness is necessary, this efficiency is very helpful.

But journals in Zones 2 and 3 deserve consideration for thorough literature reviews or major research projects. These publications might provide unique and insightful analysis lacking in main journals, therefore enhancing the knowledge of the subject. Providing a larger view of the scientific setting, peripheral journals may investigate small areas or developing trends that could become major in the future.

In Short, Bradford's Law applied to the examination of literature on digital or technological innovation for sustainable business performance offers insightful analysis of the fundamental and auxiliary sources of study. The discovery of core publications include the Journal of Cleaner Production and Sustainability (Switzerland) emphasizes the concentration of significant material found in a small number of few main sources. The increasing number of publications in Zones 2 and 3, meanwhile, demonstrates the increased interest and variety of study in this discipline. This thorough study not only makes effective literature searches easier but also emphasizes the need to include both central and peripheral sources in order to have a complete knowledge of the research landscape.

#### **4.6. Source Local Impact**

Starting with the patterns and implications of the available data for every journal helps one assess the local influence of the source. We investigate the many bibliometric indexes offered for every journal in great depth. The H index provides information on the impact of a journal within the academic community by including the number of publications from a source along with the frequency with which these works are referenced in later scholarly publications. A higher H-

index points to a noteworthy impact, meaning that its articles are regarded as important in their respective domains and have been often referenced (Hirsch, 2005).

By offering a more accurate assessment of a journal's scientific effect, the G index enhances the depth and scope of impact that papers from the journal have accomplished, therefore complementing the H index (Egghe, 2006). Turning now to the M index, this statistic further improves the H index by including the temporal element of the articles, therefore offering a rate of effect each year and gauging the journal's continuing relevance and influence over time (Meho & Yang, 2007). Our study gains depth by considering total citations, the overall number of items published by the source, and the year the source began publishing papers on technological innovations for sustainable business performance.

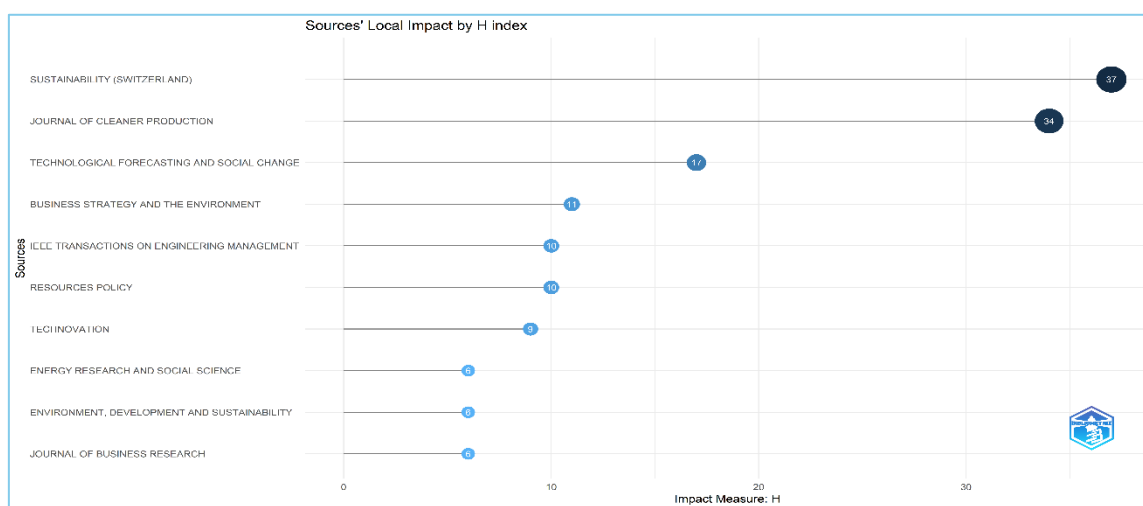


Figure 9, Source Local Impact, Bibliometrix tool

Trends like the rise of the H index over time point to growing impact and respect of the fieldwork output of the source, as seen on the scatter plot. With a H index of 37, the **Journal of Sustainability** (Switzerland) has a clear impact in the area. Starting publication in 2013, it has accumulated a significant number of citations (5499 since 2015), showing a steady level of high-quality research output that has been routinely referred by peers, therefore implying a strong resonance within the academic community. Comparably, the **Journal of Cleaner Production** has showed great influence with an H index of 34 and 4353 total citations. Though it began publishing in 2012, it keeps generating significant studies on Sustainable business practices.

Starting publication in 2021, two additional powerful publications—**Journal of Business Research** and **IEEE Transactions on Engineering Management**—have H indices of 10 and 6 respectively, with total citations of 326 and 379 respectively. Unlike commencing publishing considerably earlier, **Technovation** and **Technological Forecasting and Social Change** have lower H indices and total citations. This might be explained by the changing character of technology and how it affects environmentally friendly corporate policies (Bresnahan & Trajtenberg, 1995).

The M index provides information on the pace of reference to research published after public release. **The Journal of Business Research**, for example, has a higher M index (1.500) than **Technological Forecasting and Social Change** (0.586) and **Technovation** (0.391), therefore suggesting a quicker speed of effect even if it began publishing in 2021. Furthermore, long-standing journals like **Business Strategy and the Environment** and **Environment, Development and Sustainability** reflect the dynamic nature of the field where more recent research can rapidly become central to the continuous scholarly debate by maintaining similar H indices to more recent publications.

Analyzing the graph, the main indicators—H index, G index, M index, total citations, and publication count—align very well with the data acquired using Biblioshiny of the Bibliometrix program. Based on the H index, the scatter plot amply shows the local effect of every source, therefore verifying the major importance of publications such as **Journal of Cleaner Production** and **Sustainability (Switzerland)**. With 5499 total citations since 2013, **Sustainability (Switzerland)** for instance has a H score of 37, a G index of 61, and a M value of 3.083. With 4353 total citations since 2012, the **Journal of Cleaner Production** has an H index of 34, a G index of 65, and an M index of 2.615. Having 1233 total citations since 1996, **Technological Forecasting and Social Change** has an H index of 17, a G index of 35, and an M index of 0.586. With 746 overall references since 2004, **Business Strategy and the Environment** has an H value of 11, a G index of 15, and a M index of 0.525. With 326 total citations since 2021, **IEEE Transactions on Engineering Management** has an H index of 10, a G index of 17, and a M index of 2.5. With 302 total citations since 2017, **Resources Policy** has an H index of 10, a G score of 16, and a M value of 1.25. Having 626 total citations since 2002, **technovation** has an H score of 9, a G index of 10, and a M value of 0.391. With 257 total

citations since 2008, **Environment, Development and Sustainability** has an H index of 6, a G index of 12, and a M index of 0.353. < With 379 overall citations since 2021, the **Journal of Business Research** has a H score of 6, a G index of 6, and a M value of 1.5. These facts support the first research by verifying the great effect and impact of these publications in the field of digital or technological innovations for sustainable business performance.

The study exposes various tendencies and consequences. Core sources of high-impact research are now established by the great influence of publications like **Sustainability (Switzerland)** and **Journal of Cleaner Production**. Their great influence in shaping the conversation on technological innovation and sustainability is shown in their high H indices and total citations. The speedy rise of new powerful publications such as **IEEE Transactions on Engineering Management** and **Journal of Business Research** points to the fast-growing importance of fresh research in the sector. The fact that longer- running journals—such as **Technological Forecasting and Social Change** and **Technovation**—show lower H indices and total citations compared to more recent publications highlights the changing character of research. This tendency emphasizes the dynamic character of the area, in which research and contemporary developments are gaining importance. The mix of H, G, and M indices—which offers a whole picture of the impact of a journal—highlights the relevance of citation measures. The G score emphasizes the depth of effect, the M index provides understanding of the pace of citation over time, and the H index gauges general impact.

Finally, using bibliometric indices such the H, G, and M indices, assessing the local effect of sources offers insightful analysis of the influence and importance of journals in the area of digital or technological innovations for sustainable business performance. Consistent high-quality research outputs help core publications like **Sustainability (Switzerland)** and **Journal of Cleaner Production** to remain preeminence. Newer publications like **IEEE Transactions on Engineering Management** show how adaptable discipline is to new developments. This study emphasizes the need for the amount and quality of research outputs, thereby elevating these publications at the front of scholarly debates.

#### 4.7. Sources' Production Over Time

Understanding the development of the discipline and the rising interest in certain issues depends on an awareness of the creation of the sources over time. From 1991 to 2023, we see publishing patterns across five main sources that show little early activity followed by fast increase in recent years. There were few publications in the 1990s and early 2000s suggesting that at that time digital or technological innovations for sustainable business performance were not a priority. But in the late 2010s, each of the five main publications showed significant increase indicating that companies and the academic community had begun to concentrate on enhancing sustainable performance by means of digital technologies.

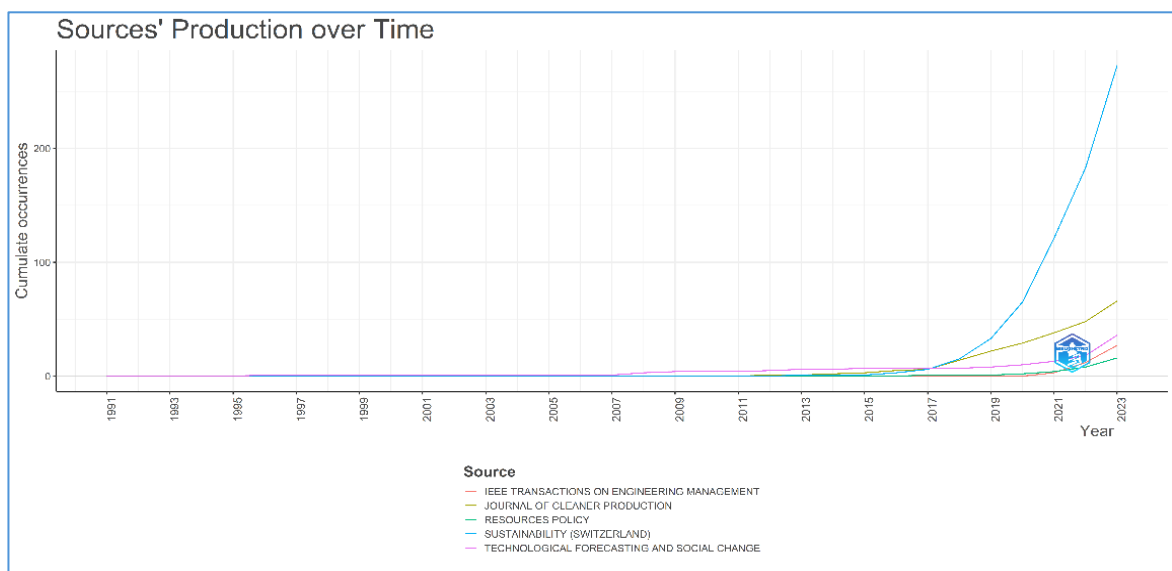


Figure 10, Sources' production over time, Bibliometrix Tool

Published a few studies in the 1990s and 2000s, “**Technological Forecasting and Social Change**” These may be inferred as pioneering studies laying groundwork for further investigations. All the main publications began covering this issue after 2016; “**Sustainability (Switzerland)**” has the most entries. According to this trend, following 2016 digital or technological innovations for sustainable business performance began to get major attention.

Particularly in the “**Sustainability (Switzerland)**” a journal, the fast expansion seen starting in 2017 illustrates the growing awareness of the significance of digital technologies in reaching environmental targets. With a notable increase in articles beginning from 2016 and peaking at 273 papers in 2023, “Sustainability (Switzerland)” has the most publications shown on the graph

and table. This journal is a main source in this sector as its concentration on sustainability issues fits very well with the studies on innovative technologies for sustainable business performance.

Beginning with a single publication in 2012 and rising slowly to 66 pieces in 2023, the “**Journal of Cleaner Production**” likewise exhibits a remarkable rise in publishing. The focus of this publication on sustainability and better manufacturing techniques fits the studies on how digital advancement could support more ecologically friendly corporate operations.

Over the years, “**Technological Forecasting and Social Change**” has consistently made contributions; from 2016 forward, it has increased notably to 36 articles in 2023. This journal is a pertinent source for study on innovations in technology and sustainability as it concentrates on projecting technological developments and their social effects.

More recently, the “IEEE Transactions on Engineering Management” began making contributions to this topic; major expansion is expected in 2021 and will result in 27 articles in 2023. The emphasis of this journal on engineering management and technology developments helps it to investigate the junction of digital breakthroughs with environmentally friendly corporate policies.

With clear contributions beginning in 2020 and rising to 16 papers in 2023, “**Resources Policy**” began publishing papers on digital technologies for sustainable performance later than the other journals. This implies that the COVID-19 epidemic could have increased the attention on digital technologies and their possible capacity to improve sustainability, thereby driving additional studies and publications in this field.

The statistics show a clear trend: publications across these important journals have surged rapidly starting in the middle of the 2010s. This might be the result of realizing during the COVID-19 epidemic the possibilities of digital and technical advancements to increase company sustainability. Both businesses and academics have discovered creative approaches to use digital technologies in corporate operations, therefore producing sustainable practices and results.

focusing on “Resources Policy,” the rise in publications starting in 2020 indicates to the pandemic condition forcing governments and policy-making organizations to develop policies improving digital technologies since their favorable influence on sustainability. The emphasis of

this publication on policy consequences fits very well with studies on macroeconomic policy consequences on how digital advances could propel sustainable behaviors.

Overall, the data reveals how from a marginal subject to a critical problem presently at the forefront of academic and pragmatic debates, technological and digital advancements for sustainable business performance have progressed. Earlier, opinions about technical progress and its use to reach sustainability were diverse. It is now established via many events and technological breakthroughs. The great rise in scholarly attention and publications reflects this development.

The study shows that academics are now actively engaged in including digital and technological innovations for sustainable business performance. The constant study and growing volume of publications point to a group effort to comprehend and improve the part digital technologies play in reaching environmental targets. This trend shows the increasing awareness of the need to combine sustainable practices with technological developments to propel environmental responsibility and company success.

To conclude, the tendency of rising publications throughout time, especially after 2016, especially highlights the growing relevance of digital technologies in reaching sustainable corporate performance. The important contributions made by publications such as “Journal of Cleaner Production” and “Sustainability (Switzerland)” underline the key role that these journals play in promoting research on this important issue. The continuous increase in research production shows a greater awareness of the need to use digital technology for sustainable business practices, an issue that will probably remain in increasing relevance in the next years.

#### **4.8. Most Relevant Affiliations**

Spread across many top universities, the most significant affiliations connected with the articles in this dataset indicate contributions from a rather worldwide spectrum of academic institutions. This underscores the universal importance of implementing technological innovations for sustainable business performance.



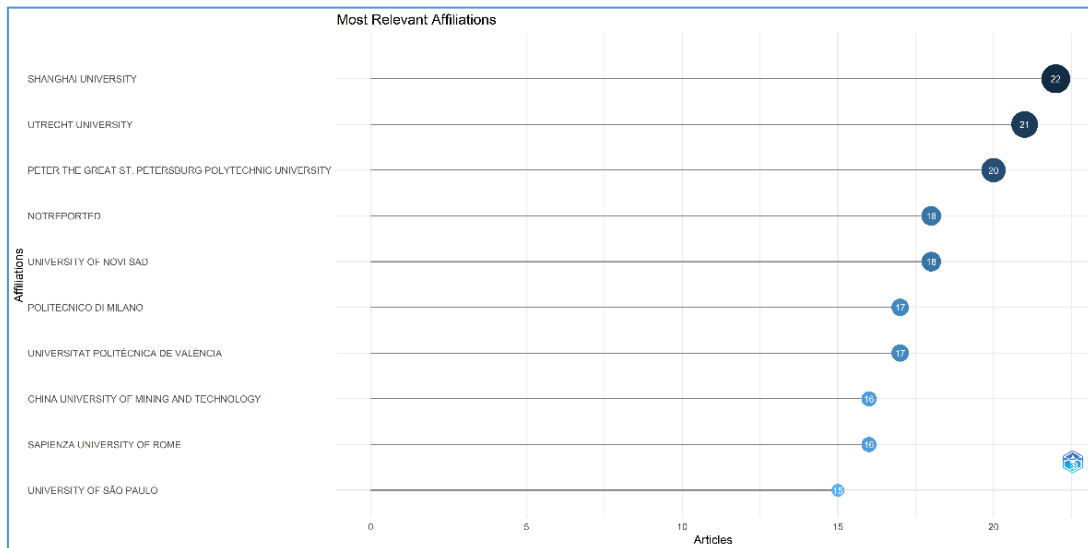


Figure 11, Most relevant Affiliations, Bibliometrix Tool

With 22 papers, **Shanghai University** leads the list; closely behind are **Utrecht University** and **Peter the Great St. Petersburg Polytechnic University** with 21 and 20 articles respectively. Nearly one-fifth of all papers in the dataset come from the top 15 most relevant affiliations, which points to a focused yet broad participation in research on the link between technological innovation and sustainable business performance.

The organizations doing this study cover America, Europe, and Asia. This geographical variety emphasizes the worldwide focus on digital or technical advancements meant to improve sustainable company performance. **Especially Italy**, China and Europe show themselves as leaders in this area. While European institutions including Utrecht University, Peter the Great St. Petersburg Polytechnic University, University of Novi Sad, **Politecnico di Milano**, Universitat Politècnica de València, and **Sapienza University of Rome** reflect Europe's strong intellectual contributions, Shanghai University's prominence is indicative of China's great role.

This topic of study is much advanced by Italian institutions, especially **Politecnico di Milano**. With 17 publications, Politecnico di Milano highlights **Italy's strong participation** in increasing knowledge of technological innovations for sustainable corporate performance. This participation emphasizes Italy's academic superiority and its part in leading original research in this field.

With its leadership in research on South America, the Brazilian institution of São Paulo stands

out as the sole institution in the top level from that country. This inclusion shows how actively South American institutions participate in adding to the worldwide conversation on innovation in technology and corporate sustainability.

In this dataset, universities predominate among the relevant relationships. This implies that, with universities leading the research effort, the topic of technological innovations for sustainable business performance is somewhat new. The dynamic character of digital developments may imply that businesses or other institutions are still in the process of properly grasping and using new technologies.

Looking at the larger list, the Politecnico di Milano and the University of Novi Sad show up as numerous more noteworthy institutions. Both universities published 17 pieces, which underlines even more the important part European institutions do in this field of study. The participation of the 16-article China University of Mining and Technology and the Sapienza University of Rome highlights even more the varied and worldwide curiosity in this topic.

The spatial and institutional distribution of the most successful connections emphasizes important regional centers and academic institutions promoting research in this topic. The concentration among the top associations exposes that while authorship is worldwide, it is not equally spread. Emphasizing their crucial importance in furthering the discipline, these leading universities are significantly adding to the body of knowledge.

Institutions from many different nations actively participating shows a worldwide endeavor to grasp and use of technologies for sustainable business success. For instance, the efforts of the Politecnico di Milano and the University of Novi Sad highlight the value of scholarly research in Europe. Institutions such as Shanghai University and the China University of Mining and Technology underline in Asia the fast development in combining digital breakthroughs with sustainable practices on this continent.

This distribution emphasizes how crucial these institutions are in forming the debate and directing further studies on how digital and technology developments affect sustainable corporate performance. Particularly in line with Italy's larger academic and industrial

capabilities, the major contributions from Italian institutions emphasize their leadership in this field of study.

In essence, the geographical and institutional distribution of the most successful affiliations reveals a worldwide curiosity and effort in investigating technologies for sustainable corporate performance. Reflecting their dedication to promoting knowledge and supporting sustainable business practices, Italian universities—especially the Politecnico di Milano—play a major part in this academic quest. This study emphasizes the important part academic institutions play in promoting research and innovation, thereby establishing them as major participants in the continuous investigation on how technologies could improve sustainable business performance.

#### 4.9. Corresponding Author's Countries

Examining the dataset of relevant authors' nations demonstrates the geographical spread of research contributions connected to digital or technological innovations for sustainable business performance. With 1,510 papers, the data emphasizes the important contributions scholars all over make.

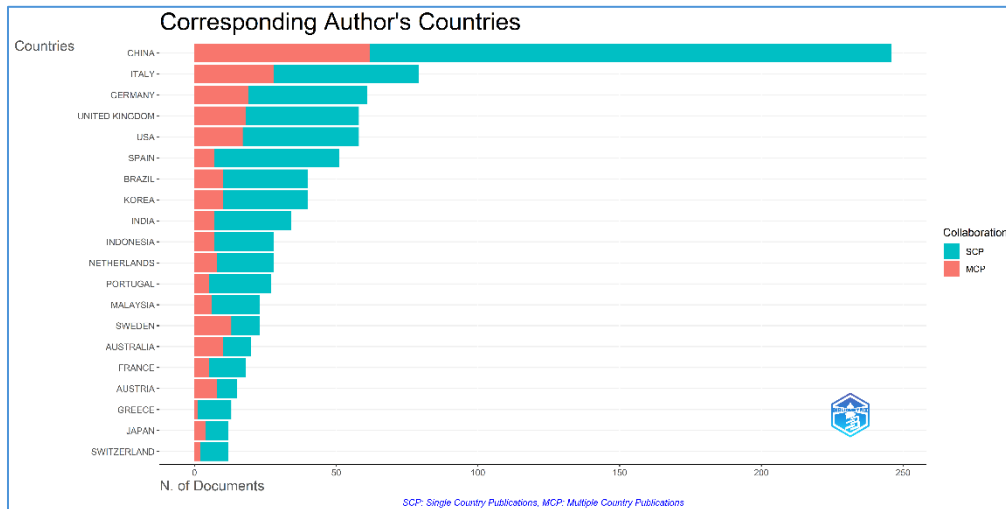


Figure 12, Corresponding authors' countries, Bibliometrix Tool

With 246 papers overall, 184 of which are single-country publications (SCP) and 62 of which are multiple-country publications; China tops the list. According to this breakdown, 25% of China's research output is produced in international cooperation while around 75% of its production is written by domestic academics. Although there is also great involvement in international collaborations, this large number of single-country publications points to the great contribution

made by Chinese researchers in this subject.

With 79 papers; 51 single-country publications and 28 multiple-country publications— Italy comes second. With over 35% of Italy's research output including co-authorship with academics from other countries, this distribution reveals a somewhat larger percentage of international cooperation than that of China. Italy's great worldwide research links in the sphere of digital and technological innovations for sustainable business performance are highlighted by this higher collaboration rate.

Germany comes next with 61 papers; the USA and the United Kingdom have each offered 58 papers. The fact that these developed nations score well points to a strong degree of creativity and a concentration on sustainability in these areas. The great volume of publications from these nations indicates their high technical capacity and dedication to solve sustainability by means of technologies.

With 51 papers, Spain also stands out as clearly making a major contribution to this field of study. Other nations making noteworthy contributions include Brazil and Korea, each with 40 papers, and India with 34 articles. These nations are developing markets with increasing focus on including technologies to improve sustainable business performance.

The statistics also show nations engaged in this study area include Indonesia (28 papers), the Netherlands (28 articles), Portugal (27 articles), and Malaysia (23 articles). These contributions from different geographical areas point to a worldwide desire in using technology for environmentally friendly corporate performance.

Examining multiple-country publications (MCP) more closely finds Sweden, Austria, and Australia leading in terms of the proportion of their overall publications including foreign cooperation. This great degree of cross-border research points to the fact that these nations respect worldwide cooperation to progress their knowledge and use of technological advances for sustainability.

Absolute numbers rank China, Italy, the UK, and the USA highest among single- and multiple-

country publications. This supremacy reflects their leadership in producing a noteworthy amount of field-based research output.

Single-country publications abundance in nations such China, India, Indonesia, Spain, Portugal, Malaysia, France, Greece, Japan, and Switzerland, pointing out a strong internal research capability. Strong domestic research systems in these nations enable significant contributions to the area without always depending on foreign cooperation.

All things considered, the dataset offers a whole picture of worldwide contributions to research on digital or technological innovations for sustainable business performance. It emphasizes the need of global cooperation in expanding this sector and the vital part developed nations play in introducing innovative sustainable business models by means of technical developments.

**Italy's strong involvement** in this field of study is shown in its leadership contribution, along with great international cooperation. The participation of Italian institutions and scholars highlights Italy's dedication to include technologies to improve corporate operations by means of sustainability. This fits the more general European emphasis on creativity and environmental sustainability.

In conclusion, the study of the nations of related authors emphasizes the worldwide significance of research on technological breakthroughs for sustainable corporate performance. Leaders in terms of publishing volume include China, Italy, Germany, the UK, and the USA. The different regional representation emphasizes the worldwide appeal and vital relevance of this field of inquiry. The active involvement of Italian scholars highlights even more Italy's strategic importance in promoting knowledge and practices that propel sustainable business performance via technologies.

#### **4.10. Countries' Scientific Production**

Analyzing national scientific output exposes a whole picture of worldwide contributions to research on digital or technical breakthroughs for sustainable business success. The large spectrum of nations in the dataset from different continents shows general interest in this topic.

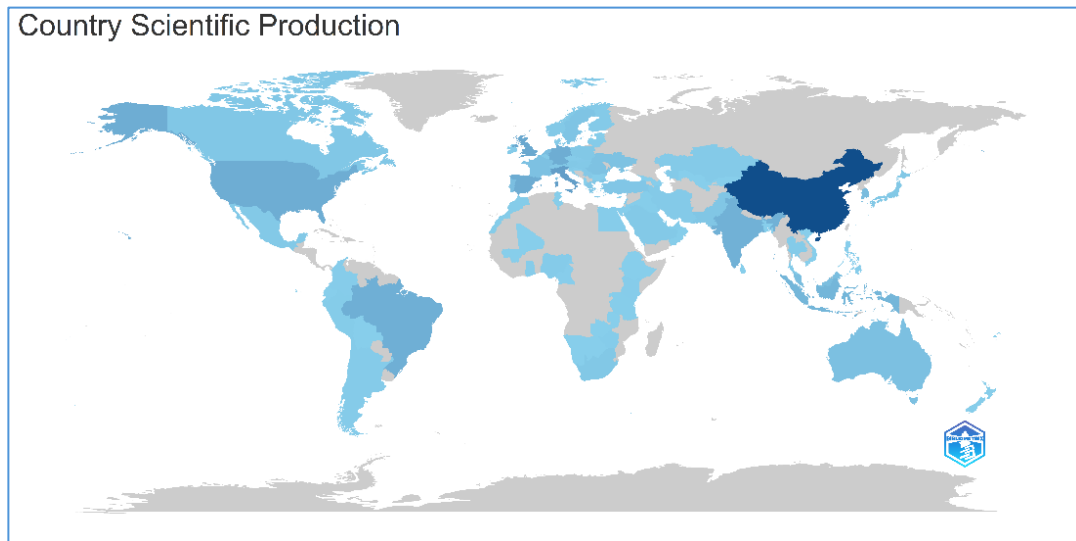


Figure 13, Countries' Scientific Production, Bibliometrix Tool

The above map graphically shows this information; deeper colors reflect nations with more publications and lighter colors indicate less publications with 812 publications, which account for more than half of all the articles, China tops clearly. This domination emphasizes China's major investment and emphasis on technological developments to improve sustainable corporate performance. China is leading this field of research thanks in great part to its strategic efforts and large expenditures in R&D.

Italy follows with 291 papers, which highlight its great dedication to innovation and environmental sustainability. The strong research output of Italian universities shows how actively the nation is in improving knowledge and practices connected to sustainable company performance by means of technological developments. Being a student at an Italian institution, it is interesting to see Italy's major contributions showing the nation's focus on using technological innovation to promote sustainability.

With 228 articles, the United Kingdom comes next demonstrating its significant interest in this area of study. The industrial backbone of the UK and favorable government policies have probably helped to foster this great degree of intellectual activity. Major contributors also include Spain (204 papers), Germany (198 papers), and the USA (198 papers). Research outputs of these nations clearly show their proactive approaches toward sustainability and innovation as well as their robust industrial sectors.

With respect to publishing counts, mid-tier nations include Brazil (186), India (171), Indonesia (146), South Korea (106), the Netherlands (99), and Malaysia (96). Reflecting increasing awareness of the relevance of this study topic, these countries are making major progress in using advances in technology to enhance sustainable business practices.

Countries in the third group, such as Kazakhstan (24 publications), Iran (23), Belgium (22), Slovenia (22), Thailand (21), Lithuania (19), Argentina (18), the Czech Republic (18), Ireland (18), Nigeria (18), Singapore (18), and Chile (16) show encouraging participation while having less publications. Their contributions point to a future possibility for expansion in the field of study as they show an increasing attention on technological innovations for sustainability.

The information emphasizes how widely people understand the need of technological innovations for sustainable corporate performance worldwide. Several elements may help to explain the different publishing counts across these nations: investment in research and development, favorable regulations for innovation, and the degree of cooperation between academics and business.

China's leadership in this area may be partially attributed to its strategic projects aiming at digital transformation and sustainability as well as significant expenditures in research and development. The great volume of publications reflects the Chinese government's determination to lead the world in sustainability and technologies. Likewise, because of their large industrial roots and regulations encouraging sustainability and innovation, European nations such as Italy, the UK, Spain, and Germany show notable involvement.

For sustained corporate success, nations such as Brazil, India, and Indonesia are realizing more and more the value of technical advancements. These countries are deliberately trying to encourage innovation in their commercial sectors to improve sustainability. The contributions from these nations mirror a worldwide trend toward adopting technological innovations to handle environmental issues.

All things considered, the worldwide landscape of research output in technological innovations for sustainable business performance emphasizes the vital part these innovations play in

promoting sustainability. The variety of contributions from many areas shows a general recognition of the need to integrate technology to achieve sustainable corporate objectives. The number of publications and the effects of these breakthroughs on sustainability should keep rising as more nations commit to research and development in this field.

#### 4.11. Countries' Production over Time

The publishing patterns of academic works on the link between technological innovation and sustainable business performance provide important information on the goals and commitments of many nations in the spheres of technology and sustainability. Examining the publication of top seven country papers over time helps us to see how the emphasis on this study field has changed worldwide.

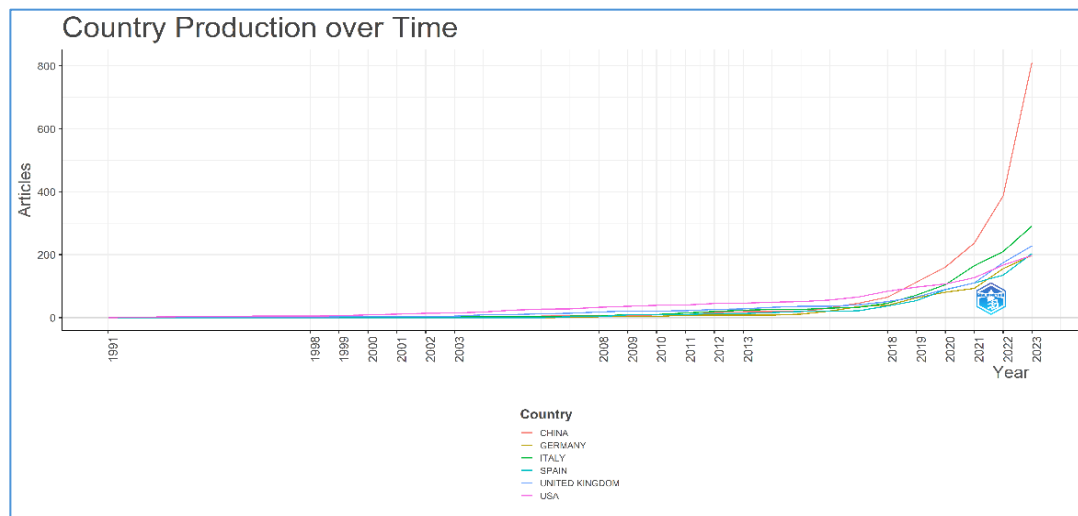


Figure 14, Countries' Production over Time, Bibliometrix Tool

Early in the field of inquiry on this subject, Italy, the United States, and the United Kingdom led. These nations showed a great will to investigate how technical and digital advances may propel environmentally friendly corporate performance. For example, the UK first wrote on this subject in 1991. The UK has generated five pieces by 2000, a reflection of consistent growing interest and research engagement. Following a similar pattern, the United States initially published papers in 1994 and progressively added 15 publications by 2005. Italy also demonstrated early participation; publications beginning in 1991 progressively increase to five publications by 2008.

With a meager beginning of only three articles, China, on the other hand, did not publish its first



piece on technological innovations for sustainable corporate performance until 2004. This late beginning implies that China first gave this field of study little priority. Still, there was a major change in recent times. China has generated roughly 4-5 times more papers since 2021. China has generated 327 papers by 2022 and an amazing 812 papers in 2023. This explosive increase draws attention to China's fresh focus on using technological innovation to improve environmentally friendly corporate operations.

While the United States, United Kingdom, Italy, and the other top nations have kept up consistent publication, their growth rates have not approached China's recent explosion. The United States had 15 articles in 2005, for example, and by 2023 that number had increased to 198 articles. Rising steadily, the United Kingdom has 228 articles by 2023. Maintaining constant increase, Italy has 291 articles by 2023. These nations have demonstrated a slower rise in their research output, indicating that earlier on they had already laid a solid basis of research in this subject. Though the speed of new publications is not as fast as China's, their steady publishing rates might suggest a continuous dedication to improving knowledge and practices at the junction of technology and sustainability.

Additionally quite active in this sector are Germany and Spain. Germany's solid industrial foundation and dedication to technological advancement help to explain its consistent growth in publications from the early 2000s. Beginning with none in the early 2000s, Germany's production rose to 156 pieces by 2022 and then to 198 items by 2023. Starting with three articles in 2008, Spain exhibited steady increase, rising to 54 articles by 2018 and then to 204 articles by 2023. This emphasizes Spain's attention on including technology for environmentally friendly business operations.

One of the early leaders, Italy has had a constant production throughout the years. The continuous efforts of the Italian scientific community emphasize the nation's long-standing interest in merging technical breakthroughs with environmental practices and its knowledge in this regard. For example, Italy's publications expanded from one article in 1991 to ten by 2009, then to 165 by 2021, then to 291 by 2023. Italy's consistent production shows a developed research environment in which basic knowledge is always growing upon.

These developments point to a dynamic change in world research objectives generally. Western nations such as the USA, UK, and Italy were first leading in investigating the connection between technological innovation and sustainable corporate performance. China's recent and fast rise in publishing, however, points strategically toward realizing the possibilities of technical advancements to provide sustainable results. Policy changes, more research and development finances, or a greater awareness of the vital part sustainability plays in long-term economic success might all help to explain this.

In summary, within the last several years the field of study on technological innovation and sustainable business performance has changed dramatically. Early leaders such as the USA, UK, and Italy set the foundation; China's recent rise highlights a major change in world research dynamics. While China's tremendous expansion alludes to a strategic catch-up and a fresh prioritizing of this important sector, the consistent production of the early leaders reveals a mature and continuous dedication. This development emphasizes the shifting emphasis and growing relevance of including technological innovations to propel environmentally friendly corporate practices all around the world.

#### **4.12. Most Cited Countries**

Examining citation data from multiple countries provides important new perspectives on scientific influence, output quality, and productivity. Better policymaking, strategic alliances, goal planning, and global knowledge landscape awareness are made possible by this information. Our study is on the link between sustainable corporate performance and technological innovation. In this regard, nations such as China, the USA, Italy, and the UK show up as the most frequently cited countries, therefore reflecting their significant contributions to this sector.

With a total of 5336 citations, China ranks first among the countries and emphasizes its great production of research. China's average citation per article, despite this great number, is 21.7, however. This much lower average implies that while China generates a lot of publications, not all of them have major influence. This trend captures China's approach of extensive research spreading across many domains within technological innovation and sustainability.

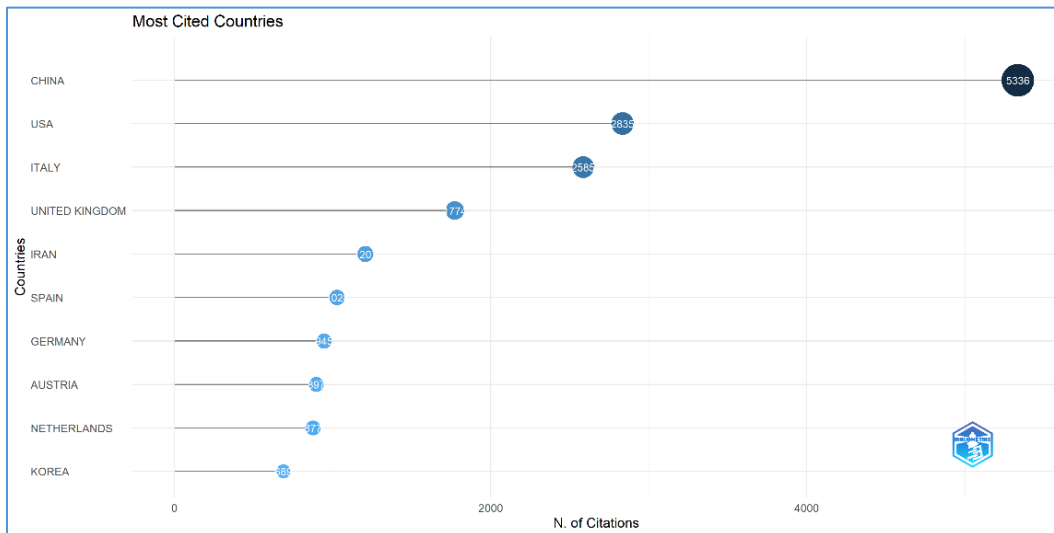


Figure 15, Most Cited Countries, Bibliometrix Tools

Following with 2835 citations and a much higher average citation per piece of 48.9 is the USA. This suggests that, per papers, American research in this field usually has greater influence. Italy also displays a balanced approach of volume and impact in its research outputs with 2585 citations and an average of 32.7 citations per publication. With an average of 30.6 citations per publication, the UK's overall citations; 1774, show its constant contribution and modest influence per publication.

Especially Iran has a high average citation per item of 172.4 even though its overall citation count is 1207. This implies that while Iran produces less research, its quality and effect are high. This trend shows a priority on generating excellent, significant research instead of concentrating only on volume.

With 945 total citations and an average of 15.5 per article, Germany shows modest output and influence; Spain has 1028 total citations and an average of 20.2. Though they have fewer overall citations; 897 and 877 respectively, countries like Austria and the Netherlands have better average citations per article; 59.8 and 31.3. This implies these nations give strong research top importance.

Though their overall citation counts are less, smaller countries such as Norway, Singapore, Hong Kong, and Lithuania also display remarkable average citations per article. For instance, the average of Singapore is 66; Hong Kong's is 62.7; and Norway's is 50.9. Emphasizing quality

over quantity, these high averages demonstrate the major influence of their research efforts.

Analyzing total and average citation counts enables us to see the wider picture of scientific influence. It emphasizes not just output but also the need for the research underdone. While individuals with high average citations show the great influence of their work, countries with high total citations are major participants in the research area. These realizations are quite essential for creating plans to improve the caliber and impact of scientific inquiry all around.

China's lower average citations per article combined with its dominance in overall citations point to a wide yet diversified influence throughout its production of research. The USA, Italy, and the UK provide balanced high-volume, highly impactful research contributions. Countries with few publications, such as Iran, Austria, and the Netherlands, concentrate on generating strong research instead.

This study emphasizes in scientific research the need of both quality and productivity. It highlights how important developed nations are in leading digital and technical advancements for environmentally friendly corporate performance. Simultaneously, it emphasizes the growing significance of smaller countries doing highly impactful research, hence augmenting the body of knowledge worldwide.

The number and influence of scientific publications should rise as more nations devote more funds to research and development; especially in digital and technological breakthroughs for sustainability. This changing landscape highlights the importance of strategic attention on creating outstanding, significant research capable of driving global sustainable business practices.

### 4.13. Most Globally Cited Documents

Analyzing the most internationally referenced papers provides important new perspectives on the influence and effect of research on technological innovations for sustainable business performance. Covering publication years 1994 to 2021, the papers in this collection have fewer than 100 to over 925 worldwide references. This wide spectrum emphasizes the development of discipline and the rising interest in combining sustainable business practices with innovations in technology.

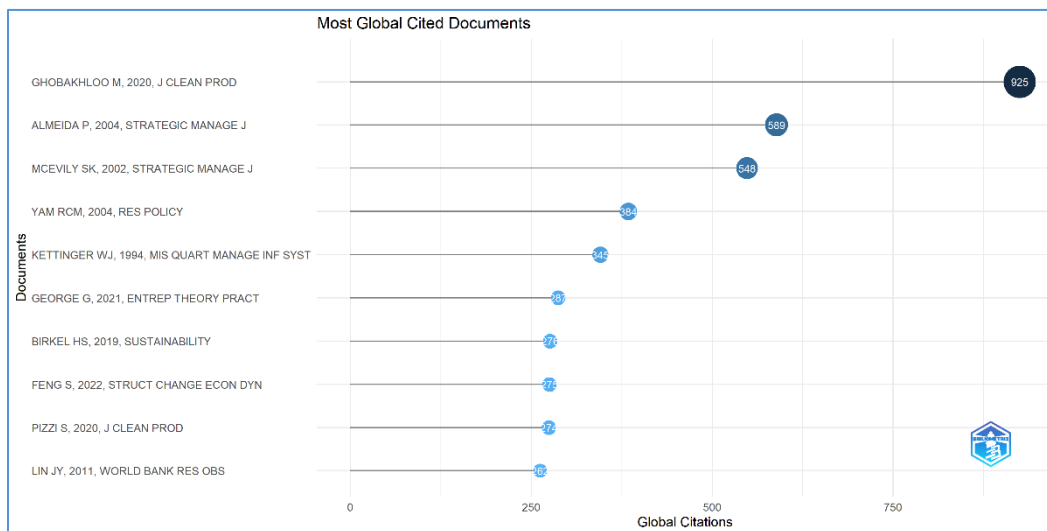


Figure 16, Most globally cited documents, Bibliometrix Tool

Published in the Journal of Cleaner Production, Ghobakhloo's (2020) top-cited publication (925 citations) really stands out. The acceptance of modern technologies by top companies in readiness for Industry 4.0 and its benefits for sustainability are covered in this work.

Emphasizing the importance of general adoption and use of these technologies to improve sustainability, it offers an interpretative model of Industry 4.0. To promote this shift, the paper advocates further investigation and legislative change.

Not far behind is Almeida's (2004) Strategic Management Journal article with 589 references. This study investigates how outside knowledge shapes innovation in global corporations. It finds that the scientific variety of the host country, the knowledge links of the subsidiary to host country companies, and the technological richness of the multinational company (MNC) greatly influence innovation. This research emphasizes the need of information sharing and technological variety in promoting innovation.

With 548 references, McEvally's (2002) work in the Strategic Management Journal looks at strategic knowledge and its role in competitive advantage. This study shows how companies may use special knowledge assets to get a competitive advantage. The results underline the important part strategic knowledge management plays in maintaining company success in a technologically advanced environment.

Published in Research Policy, the 2004 article by Yam (384 citations) looks at how companies employ information technology uniquely to create ongoing competitive advantage. It discovers that sustaining long-term success depends critically on a solid technological basis and strategic capacity. This study provides a foundational understanding of the strategic use of technology in achieving business sustainability.

With 345 citations, Kettinger's (1994) work from MIS Quarterly is the oldest among the top 10 most referenced papers. This study investigates how smart use of information technology could help companies to maintain ongoing competitive advantage. The results show the need for a strong technical foundation and strategic capacity. Although among the first research, its strong citation count suggests its fundamental importance in the subject.

With 287 references, George's (2021) work in Entrepreneurship Theory and Practice captures the current explosion of interest in this discipline. This paper investigates how entrepreneurial tactics affect sustainable company success, therefore stressing the fast acceptance and applicability of digital innovations in contemporary corporate operations.

With 276 references, Birkel's 2019 Sustainability paper explores fundamental changes in economic dynamics and their effects on sustainability. This study emphasizes the need of changing corporate strategies to fit changing technology and economic environments to meet sustainability objectives.

With 275 references, Feng's (2022) work in Structural Change and Economic Dynamics investigates how structural changes in the economy, motivated by technology developments, could result in sustainable business practices. This research underlines how companies must

adjust to these developments if they are to be sustainable and competitive.

With 274 citations, Pizzi's 2020 study in the *Journal of Cleaner Production* looks at how digital technology could improve corporate sustainability. The useful uses of digital technologies in enhancing corporate performance and reaching sustainability objectives are underlined by this study.

With 262 references, Lin's (2011) study in *World Bank Research Observer* explores the role digital and technological innovations play in economic growth. This paper offers a worldwide view of how developments in technology could propel environmentally friendly economic progress.

These highly referenced works together show the evolution and direction of study across time. Early research set the stage by pointing out important elements and building theoretical models. Building on this basis, recent studies investigate more general effects in the framework of Industry 4.0 and worldwide knowledge networks as well as pragmatic applications.

Finally, the examination of the most internationally referenced papers shows a strong and developing area of research. A great number of citations highlight the importance and influence of research on technological innovations for sustainable business performance. Achieving sustainable business practices globally will depend on ongoing research and invention in this field as the digital age develops. This increasing corpus of research emphasizes the need to include digital technologies to propel sustainable business practices and the worldwide endeavor to improve understanding and practices in this crucial area.

#### **4.14. Most Frequent Words**

The analysis of the most often occurring terms in the literature on technological innovations for sustainable business performance offers important new perspectives on the main issues and areas of concentration in this field of research. The collection exposes important terms and ideas that highlight the main goals and debates among academics.

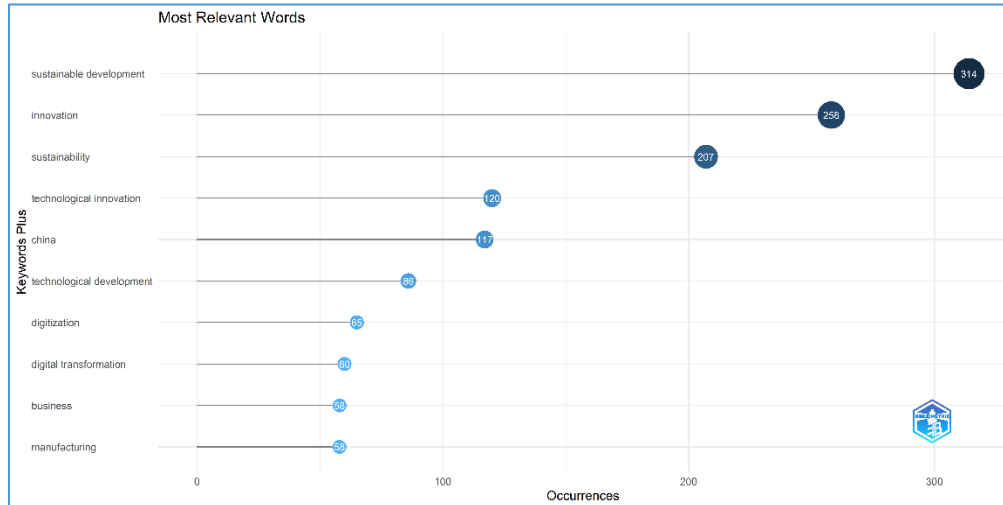


Figure 18, Most relevant words, Bibliometrix Tool



Figure 17, Word Cloud, Bibliometrix Tool.

Appearing 314 times, the phrase “sustainable development” is the most often appearing term in the collection. This great frequency emphasizes the key part sustainable development performs in the framework of corporate performance and technological innovation. The frequent reference to “innovation” (258 occurrences) and “sustainability” (207 occurrences) highlights even more the need of discovering creative ideas to reach objectives of sustainability in corporate operations.

Another important phrase is “technological innovation,” (120 occurrences), which shows a notable emphasis on the part new technologies play in producing sustainable results. With 117 events, “China” closely follows this and emphasizes the nation's major research relevance.



China's fast technological advances and strategic focus on sustainable development have made it a major participant in this field as shown by the great frequency of its citation.

The word “technological development” shows 86 times, which reflects the continuous improvements and use of fresh technology in many corporate operations. Likewise, “digitization” (65 events) and “digital transformation” (60 events) underline the change toward digital technology and their transforming power on corporate operations. These phrases capture the change companies are going through to include digital solutions for improved performance and sustainability.

With each appearing 58 times, “business” and “manufacturing,” both show that these industries are main ones where technology breakthroughs are being used to provide sustainable results. The 47 times reference of “supply chain management” points to the need of giving supply chains top priority in terms of technological optimization. Reducing waste and raising sustainability in corporate operations depend on effective supply chain management.

With 46 instances, the phrase “competition” suggests the competitive advantages companies search for by means of technology developments and environmentally friendly policies. Sustainable innovation offers businesses a competitive advantage by helping them to stand out from one another. Further underlining the strategic element of including sustainability into corporate growth and management choices are “business development” (40 events) and “decision making” (35 events).

Each cited 35 times, “stakeholder” and “small and medium-sized enterprise” (SME) emphasize the need of addressing many stakeholders in the sustainability process and the major part of SMEs in implementing sustainable practices. Using technological advancements for sustainability presents special possibilities and difficulties for SMEs.

Other noteworthy phrases, illustrating the wider repercussions of technological developments beyond the company itself, include “economic and social effects” (32 occurrences). Each appearing thirty times, the emphasis on “environmental protection” and “economic growth” highlights the double focus on achieving environmental sustainability while boosting economic

success.

With thirty instances each, “planning,” “strategic approach,” and “environmental management” all show how important strategic planning and management are in reaching environmental objectives. Companies are using methodologies designed for integration of sustainability into their long-term plans more and more.

The phrases “circular economy” (71 occurrences) and “climate change” (26 occurrences) capture the rising awareness of sustainable economic models and the immediate need to solve climate change. Essential for sustainable business operations, the circular economy focuses on reducing waste and optimizing resource efficiency.

Furthermore pointing to a comprehensive perspective of sustainability including technical, social, and environmental aspects are words like “technology adoption” (26 occurrences) and “corporate social responsibility” (25 occurrences). These words emphasize the many strategies companies must use to achieve actual sustainability.

Finally, the study of the most often occurring terms in the literature on technological innovations for sustainable business performance exposes a whole and linked perspective of the research landscape. The common expressions highlight the important link between innovation and sustainability, the major influence of technological developments, and the more general effects on social and economic spheres. This study offers insightful analysis of the main issues influencing research and practice in this subject, stressing the need of integrating technological innovations with sustainable business strategies to build a strong and sustainable future.

#### **4.15. Words’ Frequency Over Time**

Studying word frequency over time offers insightful analysis of developing trends and helps one determine which ideas are becoming popular and at what speed. This study helps us to grasp the change of the research emphasis in the framework of technological innovations for sustainable business performance.

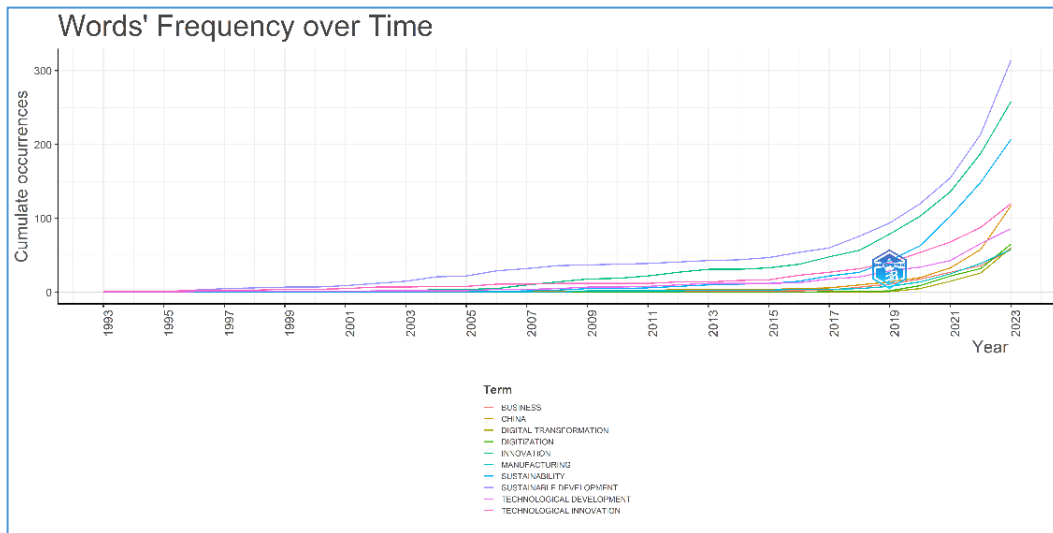


Figure 19, Words Frequency over Time, Bibliometrix Tool

Early studies on this subject, between 1993 and 2000, most often used terms were “sustainable development,” “technological innovation,” and “technological development.” This suggests early on experts were already investigating the link between sustainability and technological progress. These are always evolving terms that are still very relevant now. The regular recurrence of these words implies that the fundamental ideas of connecting sustainability with technological developments have remained a key focus in this field of study.

Originally first used in the early 2000s, “innovation” and “sustainability” have witnessed ongoing rise in popularity. Among the three most often used terms by 2023 will be these ones. This trend suggests that technological innovations are becoming more and more acknowledged as vital means of reaching sustainability. This development shows a wider knowledge and respect of how creativity may provide sustainable results, which is essential to solve world environmental and financial issues.

More recently, the phrases “digitization” and “digital transformation” surfaced in the literature; 2017 and 2019, respectively. Reflecting the great influence of Industry 4.0, the arrival of high-speed internet like 5G, and other digital services, they have been dominating terminology since they first appeared. This change shows that while at first thought linked, researchers now separate technological and digital advances as they develop, therefore creating separate branches from each other. Understanding the effects of different innovations in technology on sustainable business practices depends on this difference.

Beginning in 2006, the word “China” became very common and has kept on increasing. This trend implies that either a sizable amount of study in this sector is being done by Chinese researchers, or worldwide scholars are using China as an example and innovator for technological innovation for sustainable company performance. China is a major focus in research analyzing the junction of technological innovation and sustainability because of its fast technological advancement and growing attention on sustainable development.

Over the years, the word “business” has often come up as studies on this subject are either done in a commercial environment or directly connect to business groups. This constant presence emphasizes how important business performance is for research of technological innovation connected to sustainability. The constant reference to “business” emphasizes the pragmatic uses and consequences of this study, therefore guaranteeing that it tackles possibilities and problems of the corporate sector.

All things considered, the frequency of terms throughout time shows notable patterns and changes in the emphasis of research on digital and innovative technologies and their influence on sustainable business success. Key phrases like “sustainable development” and “technological innovation” are always quite relevant, as their continual popularity emphasizes. Concurrent with this, the emergence of phrases like “digitization” and “digital transformation” emphasizes how dynamically changing technology is and how it may be used to reach sustainability. The increasing reference to China suggests its vital importance in this field of study; the continuous usage of “business” shows the useful use of these developments in the commercial sector. These patterns taken together provide an overall picture of how the debate on technological innovation for sustainable business performance has changed with time.

#### **4.16. Trend Topics**

Looking at word frequency across years offers important new perspectives on the evolving goals and areas of focus in the realm of technological innovation for sustainable company success. This study emphasizes developing patterns and clarifies the change of research emphasis. The study subject can be separated into three separate eras depending on the trends: 1991 to 2010, 2010 to 2018, and 2019 to the present.

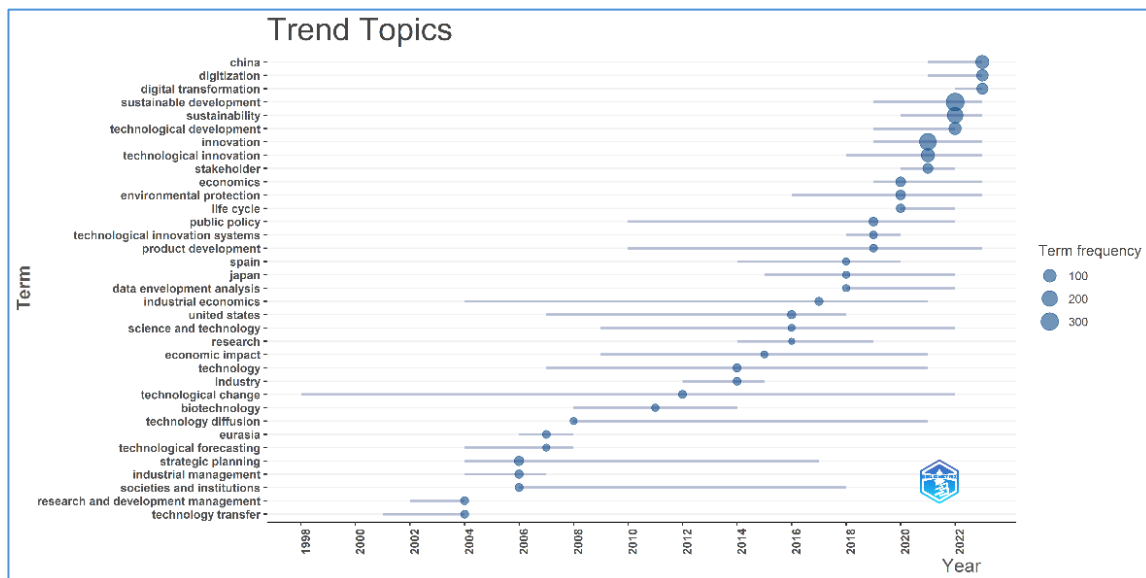


Figure 20, Trend Topic, Bibliometrix Tool

Research on technological innovations was in their early years between **1991 and 2010**. Technology had not yet completely evolved, and researchers lacked exact data to demonstrate the influence on company success. As such, they concentrated on projecting the influence and offering a summary of the possible technological advancements. Important subjects during this period included “technological forecasting,” “technology transfer,” “strategic planning,” and the social and economic consequences of technology. This age marks a period when very few nations could afford major developments and technology was not fully acknowledged. Researchers spoke about the possible advantages of technology transfer from developed to developing areas as well as how to spread innovations in technology throughout many industries. Much of the study was theoretical since technological progress was still in its infancy, concentrating more on projecting than on exact measurement.

Technologies were more advanced in the years **2010 to 2018**, but businesses adopted them slowly since upgrading current systems proved difficult. Clearer knowledge among researchers enabled them to quantify the effects of these technologies. During this time, “technological change,” “data development analysis,” “economic impact,” and the interaction between “industry” and “technology,” were trending subjects. This development suggests that companies and scholars may now track how technology affects industrial performance economically. This was a period of notable technological advancement with major transformations in many different fields. Businesses realized they needed to include these ideas in their processes if they were to

improve competitiveness and efficiency. The emphasis of the study changed from theoretical forecasts to actual implementations and the observable advantages of technology acceptance.

Particularly shaped by the COVID-19 epidemic, the year **2019 to the present** has witnessed the most significant effort on this subject. Businesses were driven to use digital technologies, therefore underscoring the actual possibilities of technology and its effects on sustainability. Topics trending right now include “digitization,” “digital innovation,” “lifetime sustainability,” “digital transformation,” and “China.” This is the age when businesses were compelled to embrace digital technology and then discovered their full potential and effect on sustainability. Terms like “public policy” suggest that governments are also pushing companies to use digital technology because of their benefits. As companies adjusted to remote labor and online operations, the epidemic hastened digital transformation and spurred major study on how these developments may assist environmentally friendly business practices.

Reflecting its ongoing importance in research, the phrase “sustainable development” has demonstrated steady increase. It emphasizes how to achieve long-term sustainability by incorporating social, financial, and environmental objectives. Still the pillar of research, “technological innovation” emphasizes continuous attempts to create new technology capable of driving environmentally friendly corporate practices. The rising awareness of the part innovation plays in reaching sustainability is shown by the ongoing rise in the use terms “innovation” and “sustainability”. Researchers are especially interested in how creative ideas could solve environmental problems.

Introduced in recent years, the concepts “digitization” and “digital transformation” have rapidly taken front stage in reflection of Industry 4.0 and developments like 5G. They indicate the shift toward more complex digital solutions for corporate operations. The prevalence of the phrase “China” points to the nation's major influence on sustainable business practices and innovations in technology. It emphasizes China's impact on world research and its commitment in green technology. The persistent usage of “business” throughout the years suggests that research is intimately connected to useful corporate applications. To attain sustainability, it underlines the need of integrating advances in technology into corporate plans.

In general, the frequency of terms throughout time shows notable trends and changes in the emphasis of research on technological innovation and their influence on sustainable business performance. While the rise of terms like “digitization” and “digital transformation” highlights the changing nature of technology and their uses in attaining sustainability, the constant prominence of key terms like “sustainable development” and “technological innovation” highlights their enduring relevance. The increasing reference to China suggests its vital importance in this field of study; the continuous usage of “business” shows the useful use of these developments in the corporate sector. These patterns taken together provide a whole picture of how the debate on digital and technology innovation for sustainable corporate performance has changed with time.

#### 4.17. Thematic Map

Key study topics resulting from academic articles on the link between technological innovations and sustainable business achievement are visually shown on the thematic map. This study offers a thorough picture of the many topics in this field of research by use of biblioshiny of bibliometrix software.

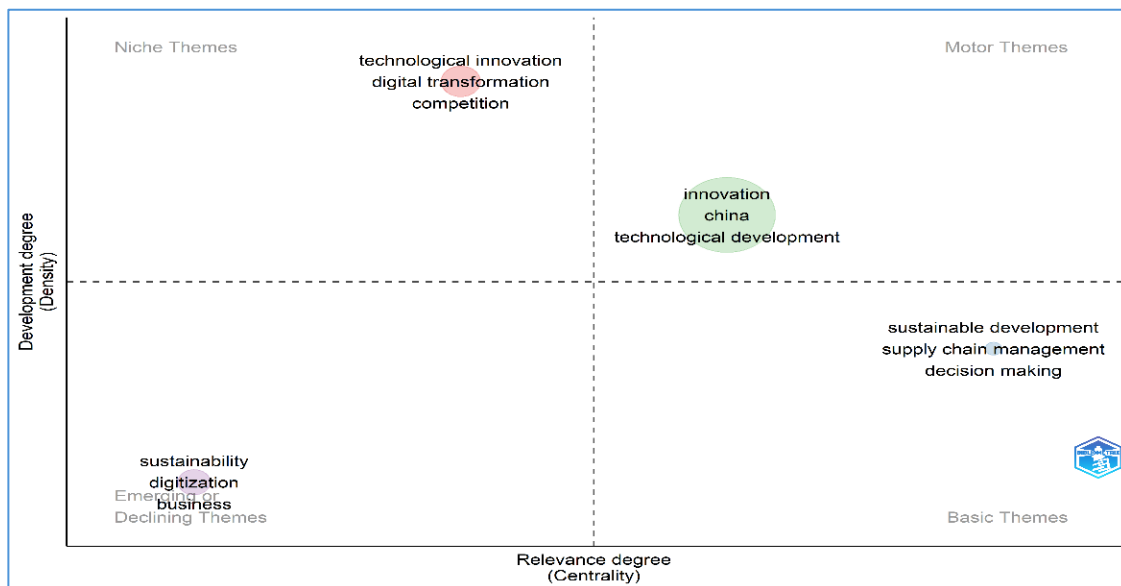


Figure 21, Thematic Map, Bibliometrix Tool

Two dimensions define the plots: the horizontal axis shows the relevance degree (or centrality) to the subject; the vertical axis shows the development degree (or density) of research on that issue. Labeled “Motor Themes,” in the upper-right quadrant we see topics like “Innovation,” “China,”

and “Technological Development.” The literature's essential and well-developed themes point to their maturity and basic nature in the discipline. Their positioning implies they are extensively debated and regarded as essential for comprehending the larger conversation on technological innovations for sustainable corporate performance. The great centrality and density of these subjects highlight their significance as well as the abundance of studies done on them. These issues are fundamental in the sector and inspire both theoretical and pragmatic developments in knowledge of how new technologies could enhance environmentally friendly corporate operations.

On the lower-left quadrant, designated “Emerging or Declining Themes,” we discover topics like “Sustainability,” “Digitization,” and “Business.” These subjects can be fresh regions that have not yet been thoroughly investigated or they might be previously mentioned but less often studied topics. Examining the terminology

From “sustainability” and “digitization,” we might deduce that these are only starting subjects of inquiry. Reflecting their rising relevance in the framework of technological innovations, they are projected to be profitable sectors of activity in the future. Though not yet completely defined, these topics draw attention to changing interests and possible future study paths. They give chances for innovative research and ideas that could change existing knowledge and methods in the sector.

Though they have low centrality, the “Niche Themes” in the upper-left quadrant—like “Technological Innovations” and “Digital Transformations”; show a great development degree. This implies that even if a lot of study has been done in these fields, they are not as important for the key debates on technological innovations for sustainable business performance. Their stance, however, touching the first quadrant (Motor Themes), suggests that they have the potential to be mature and fundamental subjects. Given our studies on these subjects, this possibility is very pertinent. The significant volume of research in these fields points to a profound, but somewhat secluded, inquiry that, as the topic develops might be more completely included into mainstream debates.

Finally, while having low density, concepts in the “Basic Themes” quadrant, such as



“Sustainable Development,” “Supply Chain Management,” and “Decision Making”; show great importance. This suggests they are vital for the field’s conversation but could need further literary development to provide a stronger body of evidence. Though more thorough study is necessary to completely prove their relevance, these topics are essential for comprehending the fundamental elements of how technological and digital breakthroughs could generate sustainable corporate success. While the necessity of further development emphasizes chances for deeper research and contribution, the prominence of these subjects emphasizes their relevance.

A strategic tool for determining which fields of inquiry want more academic attention and which are already saturated is this theme map. By stressing mature issues, new trends, and areas requiring further in-depth investigation, it helps to orient next research paths. Knowing the location and degree of development of these themes helps researchers concentrate their attention on subjects either important for the area or ready for further study. Thus, the map provides insights on the present situation of research and points to possible future advancements, thereby acting as both a diagnostic and a predictive tool.

#### **4.18. Co-occurrence Network**

In the field of technological innovations and sustainable business performance, the co-occurrence network offers a whole picture of how many ideas and topics are linked. Larger nodes in this image indicate words with more frequency or relevance in the texts; the clusters of related phrases show here. The degree of the co-occurrence connection is reflected in the thickness of the lines separating nodes, therefore providing information on the links among many study subjects.

Represented in red, **Cluster 1** is mostly dominated by phrases connected to fundamental ideas such digitalization, technological innovation, and their implementation in corporate firms. This cluster emphasizes the critical part that innovations in technology play in inspiring business sector innovation. From the acceptance of fresh digital tools to the use of sophisticated technologies like artificial intelligence and blockchain, technological innovation covers a vast spectrum of advances. Businesses trying to maintain a competitive edge and improve their operational efficiency depend on these developments.

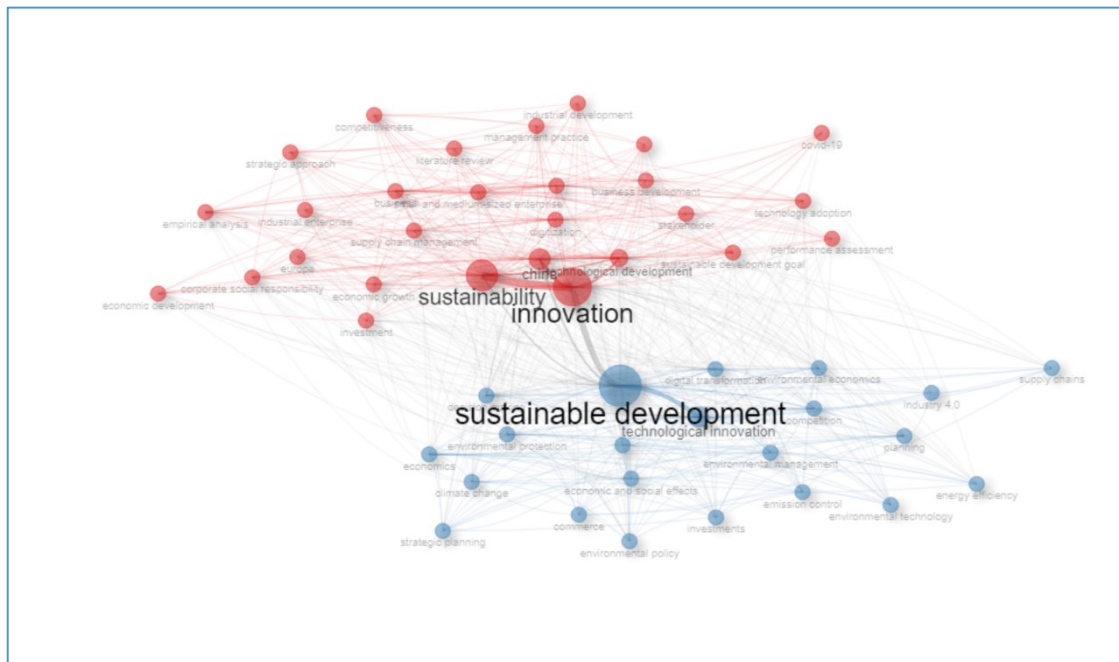


Figure 22, Co-occurrence Network, Bibliometrix Tool

Conversely, **Cluster 2**; shown in blue, focusses more on performance criteria including environmental effect, sustainable development, and environmental policy. This cluster underlines the increased focus on sustainability and the consequences of corporate activities on the surroundings. For companies trying to match their plans with world environmental objectives, sustainable development is progressively taking the stage. Companies today are more than ever being held responsible for their environmental impact; measures meant to lower carbon emissions and support resource efficiency are starting to gather support.

The betweenness centrality value shows the frequency of a node on the pathways linking other nodes. Higher betweenness nodes are often seen as significant as they link many pathways in the network. With the greatest betweenness centrality in Cluster 1, “innovation” indicates that it is a vital link in the literature bridging many ideas of digital or technological developments to sustainable business success. This suggests that innovation is a fundamental topic connecting innovations in technology with their useful relevance in corporate environments, therefore promoting sustainable performance. With the greatest betweenness centrality in Cluster 2, “sustainable development,” it is clearly important for connecting many issues about sustainability. Emphasizing its natural importance in the debate on environmental sustainability, sustainable development acts as a link between many environmental policies and impact assessments.

A node's closeness centrality score shows its degree of connectivity to every other node in the network. A greater proximity score implies that a node can effectively disseminate information around the network. Examining both groups, concepts like "sustainable development," "innovation," "technological development," and "sustainability" had closer scores. This highlights their significance and efficiency in spreading knowledge throughout the network, therefore underlining their indispensable responsibilities in the debate on technological innovation for sustainable business performance. These words have high proximity centrality ratings, which underline their frequency in literature and imply that these ideas are well-integrated and essential for comprehending the larger research landscape.

PageRank is another crucial statistic that shows the importance of a node by reflecting the probability of accessing it via random walk within the network. Highest PageRank scores are for "sustainable development," "innovation," "sustainability," and "technological innovation." This implies that these nodes are very powerful within the network, so these phrases are not only often happening but also quite important in linking many facets of digital or technological innovations for sustainable business success. These phrases' high PageRank values confirm their significance and imply that they are main subjects of research interest.

Acknowledging the importance of incorporating digital innovation into corporate plans in recent years has helped to explain why sustained success is obtained. Many times, digital tools and technology provide chances for companies to increase their environmental impact minimization, waste reduction, and efficiency enhancement. By means of real-time data on energy usage and operational inefficiencies, Internet of Things devices, for instance, might improve resource management. Blockchain technology may also increase supply chain transparency, therefore guaranteeing that companies follow sustainable practices.

Moreover, the co-occurrence network exposes that the literature heavily relies on words connected to policy and regulation, including "environmental policy." This emphasizes how crucial regulations are in pointing companies in the direction of sustainable behavior. Good environmental legislation may motivate businesses to embrace creative technology, lowering their environmental impact. Therefore, governments and regulatory authorities play a very

important part in creating the conditions that encourage innovative technology for sustainability.

Finally, the co-occurrence network analysis offers insightful examination of the connections among innovation, advancements in technology, and environmentally friendly corporate performance. Crucially important and acting as links between many ideas in literature are innovation and sustainability. This study emphasizes the importance of continuous research to investigate the interactions between sustainability and technological advancement, therefore directing companies toward more ecologically friendly methods. By keeping these important areas of concentration, academics may help to create plans that not only improve corporate success but also support social responsibility and environmental preservation.

#### 4.19. Co-citation Network

The co-citation network study of technological innovation for sustainable business performance provides a whole perspective of the intellectual terrain within this subject. By looking at how often pairs of papers are mentioned together, co-citation analysis; a potent bibliometric technique that allows researchers to spot important themes, eminent authors, and the change of study areas. This approach clarifies the important works supporting a certain study subject as well as the fundamental literature.

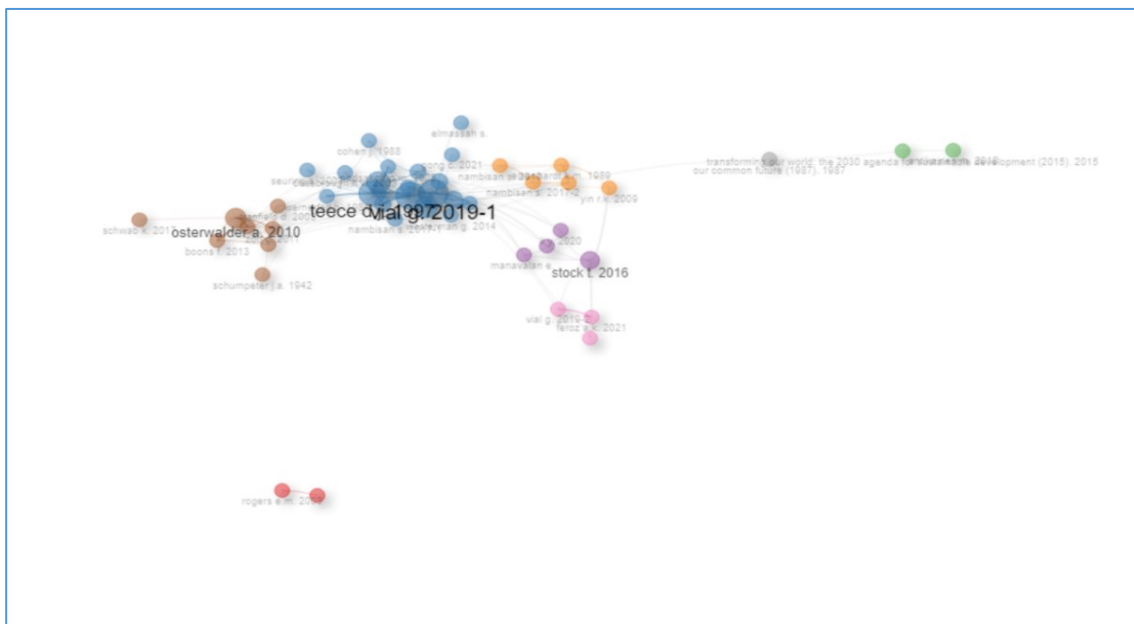


Figure 23, Co-Citation Network, Bibliometrix Tool

The co-citation network's depiction exposes many nodes and links wherein each node denotes an academic work like a journal article, conference paper, book, or other publication. Every node's size denotes its citation effect; bigger nodes imply more often referenced works. The lines linking the nodes indicate co-citations; that is, the linked works have been referenced collectively in one or more publications. These lines' thickness shows the frequency of co-citations; bigger lines indicate more often occurring co-citations. Various colors in the network indicate different clusters, each stressing a theme topic or subfield within the larger study area.

Seen in **blue**, one of the main clusters in the co-citation network is around works emphasizing digital transformation, dynamic capabilities, and business model innovation. Important publications in this cluster include Vial's (2019) thorough assessment of digital transformation literature, which addresses how strategically, and operationally digital technologies affect companies. Emphasizing the need of dynamic skills for companies to adapt and flourish among technological advances, Teece's (1997) foundational work on these abilities is likewise fundamental to this cluster. Osterwalder's (2010) framework for business model innovation is another powerful piece in this cluster that offers vital understanding of how companies could use technological advancements to generate, distribute, and seize value. Representing the basic ideas and frameworks driving contemporary research in this field, this core cluster is crucial in understanding how technology could improve company performance and sustainability.

Represented in **green**, another important cluster is around sustainability frameworks and worldwide ambitions. Among the notable publications in this group are "Our Common Future" (1987) and the 2030 Agenda for Sustainable Development (2015). Comprising the Sustainable Development Goals (SDGs), the 2030 Agenda offers a worldwide call to action to eradicate poverty, safeguard the earth, and guarantee wealth for everyone. Integrating technological innovations within the more general framework of sustainable development objectives depends on this topic. Published in 1987, "Our Common Future" is a foundational study that first proposed the idea of sustainable development and set the framework for much of the modern conversation on environmentalism. To handle urgent environmental and social issues, this cluster emphasizes the need to match technological innovations with worldwide sustainability objectives.

Seen in orange, a third cluster focuses on entrepreneurial ecosystems, organizational transformation, and innovation management. Important works in this cluster include Schumpeter's (1942) on creative destruction, which stresses the part innovation plays in economic growth. Especially noteworthy is the 2000 debate on dynamic capacities in volatile contexts by Eisenhardt and Martin, which emphasizes the tactics companies must use to control change. The 2017 research on digital entrepreneurship ecosystems by Nambisan enhances this cluster even further by offering understanding of how digital technology could support entrepreneurial activity. This cluster emphasizes how crucial it is to properly use technology for sustainable corporate performance by means of organizational transformation and management of innovation.

Further network insights come from metrics such as betweenness centrality and PageRank. With high betweenness centrality nodes like Vial (2019) and Teece (1997) serving as bridges that enable information transfer, betweenness centrality shows the function of a node in linking several sections of the network. Based on their connectedness, PageRank gauges the impact of nodes; highly linked works such as Vial (2019) have especially shaped contemporary academic debates.

This study reveals some quite well-known tendencies and topics. Emphasizing its strategic influence on business models and operations, digital transformation helps companies to change and flourish in the digital world. Maintaining competitive advantage among technological changes depends on dynamic capacities, which are therefore clearly important. Creating, distributing, and collecting value from technological innovations depend on business model innovation. Emphasizing the integration of technological developments within the framework of world sustainability agendas, there is also growing awareness of the need to match technological advances with sustainability objectives.

## **5. Key findings and Conclusion.**

In this thesis, we have tried to examine the scholarly landscape of the topic “sustainable technological innovation for sustainable business performance” through a bibliometric analysis of 1,510 scholarly papers spanning more than three decades. In summary, the following points outline the research landscape in this area.

First, in line with the worldwide emphasis on sustainability and digital transformation, research on sustainable technological innovation has seen notable increase since 2017. The yearly scientific output shows a growth in publications; 2021 stands out as particularly significant, which fits the growing incorporation of sustainable technology into corporate operations. This development points to a changing focus in both academics and business toward the strategic use of technology to meet environmental targets.

The analysis reveals that the most frequently cited themes are “digital transformation,” “technological innovation,” and “sustainable development.” These themes are central to ongoing research, reflecting the critical intersection of technological advancements and sustainability practices. The study identifies a few key authors, such as Ghobakhloo M., Kumar A., and Zhang Y., as influential contributors to the field, underlining the importance of collaborative, cross-disciplinary research.

With *Sustainability* (Switzerland) and the *Journal of Cleaner Production* being leading publications on sustainable technological innovations, the study also emphasizes important scholarly publications driving the conversation in this area. Studies on the integration of cutting-edge technologies, including artificial intelligence, the Internet of Things, blockchain, and renewable energy; into sustainable business practices often feature in these publications.

Networks of co-authorship and cooperation show a great degree of worldwide cooperation in this field of study. This emphasizes the worldwide character of the sustainability problem, which calls for a group effort across boundaries to create and apply technologically sound solutions properly. Citation analysis also reveals that highly cited publications, like those by Vial (2019) and Teece (1997), provide basic models for comprehending how technological innovation shapes organizational sustainability and competitive advantage.

Overall, this bibliometric study shows that sustainable technological innovation is a vibrant area of research with increasing attention on practical uses. The results imply that the scholarly community is realizing more and more how important technological innovation is to propel sustainable business performance. The study underlines also the need for ongoing interdisciplinary research to handle the complexity of combining technology with environmental policies. This thesis presents a thorough summary of present research trends and emphasizes the

main ways in which technological innovation might support sustainable development, therefore influencing corporate practices.

## **6. Limitations and scope for further studies.**

There are some limitations in our research on sustainable technological innovation that future researchers may be able to address. The primary limitation is the dependence on bibliometric analysis, which, while providing insightful information on academic trends and publishing statistics, could not completely reflect the nuances of practical application throughout many sectors and areas. This research is limited to papers found in the Scopus database, hence research published in other important databases or gray literature may be underrepresented.

Another limitation is the emphasis on certain technical developments, such as artificial intelligence, blockchain, and renewable energy—while maybe undervaluing other developing technologies like biotechnology or advanced materials, which might equally significantly affect sustainability. Furthermore, the study mostly emphasizes successful case studies from big multinational companies, which could not fairly depict the difficulties small and medium-sized businesses (SMEs) have implementing sustainable technological innovations.

Regarding the extent of further research, future studies should investigate more thorough empirical studies including other sectors, particularly SMEs and developing countries, where the obstacles to technological innovation may vary. More practical insights might also come from investigating how public policy, regulatory frameworks, and international collaboration could support sustainable technological innovation. Finally, longitudinal research looking at how these developments affect sustainability performance could provide a better knowledge of their efficiency throughout time.



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