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The Evolution of Sustainability Research in the Semiconductor Industry: Trends, Knowledge Structures, and Future Research Directions

Abdullah

p22ee001@iitj.ac.in

Indian Institute of Technology Jodhpur https://orcid.org/0000-0001-9487-2595

Aliza

Banaras Hindu University

Systematic Review

Keywords: Sustainability, Semiconductor industry, Bibliometric analysis, Circular economy, ESG, Sustainable manufacturing, Decarbonization, Sustainable manufacturing, VOSviewer, Biblioshiny

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The Evolution of Sustainability Research in the Semiconductor Industry: Trends, Knowledge Structures, and Future Research Directions

Aliza[1]
[1]*Faculty of Commerce*
[1]*Banaras Hindu University, U.P., India, 221005*

Abdullah[2*]
[2]*Department of Electronics Engineering*
[2]*Indian Institute of Technology Jodhpur, Jodhpur-342030, Rajasthan, India*
**Corresponding Author: p22ee001@iitj.ac.in*

Abstract

Purpose – The semiconductor industry faces increasing pressure to balance technological advancement with environmental sustainability. This study aims to examine the evolution of sustainability research in the semiconductor industry and identify its intellectual, conceptual, and social knowledge structures.

Design/methodology/approach – A bibliometric study was performed by using 734 publications indexed in Scopus during 2000-2026. BiblioShiny and VOSviewer were used for performance analysis and science mapping techniques like co-authorship analysis, co-citation analysis, citation analysis, and keyword analysis.

Findings – The results reveal a substantial growth in research output over the study period, with China, India, and the United States emerging as major contributors. Keyword and density analyses indicate that sustainability, semiconductor manufacturing, sustainable development, recycling, and environmental management constitute the core research themes. Co-authorship and co-citation analyses suggested need for international collaboration and interdisciplinary knowledge exchange. Furthermore, topics related to circular economy, supply chain management, renewable energy applications, and resource efficiency suggest promising directions for future sustainability research in the semiconductor industry.

Research limitations/implications – The study is limited to Scopus-indexed publications and selected subject areas, which may exclude relevant studies from other databases.

Practical implications – The findings provide valuable insights for researchers, industry practitioners, and policymakers by identifying key sustainability themes and emerging areas that can support sustainable transformation within the semiconductor industry.

Originality/value – This study offers a comprehensive bibliometric overview of sustainability research in the semiconductor industry by integrating performance, social, intellectual, and conceptual structure analyses, thereby providing a foundation for future research and policy development.

Keywords: Sustainability; Semiconductor industry; Bibliometric analysis; Circular economy; ESG; Sustainable manufacturing; Decarbonization, Sustainable manufacturing, VOSviewer; Biblioshiny.

1. Introduction

The semiconductor industry constitutes the foundation of contemporary technological innovation, including artificial intelligence, telecommunication, consumer electronics, renewable energy, and the fourth industrial revolution (**Mullen and Morris, 2021; Cho and Ju, 2023**). Due to the fast pace of technology development, the market of semiconductors has expanded significantly over the past several years (**Shen and Tsai, 2022**). This industry is highly relevant for the fields of automotive, health care, electronics, and communications, and there

are also countries, such as China, Taiwan, and the US, that invested heavily in the development of semiconductors and related research (**Chaudhuri et al., 2024; Cho and Ju, 2023**). Additionally, the high-quality development of semiconductor companies has significant implications for economic growth (**Li and Yang, 2026)**.

Although this sector holds a lot of economic value, semiconductor production is characterized by high energy use, water consumption, toxic chemical usage, and greenhouse gas emission. This leads to the presence of substantial environmental problems (**Chaudhuri et al., 2026**). Climate change, resource scarcity, and pollution issues are becoming major issues for the sector (**Bardon et al., 2020; Gocyla et al., 2026**). As a result, companies operating in this industry have taken sustainable practices in areas such as energy efficiency, carbon reduction, renewable energy, and environmental governance into account. Nevertheless, the effect of the sustainability practices on the business performance and efficiency of the enterprises is unclear (**Sun et al., 2024**). Although it is found that sustainability disclosures and supply chain networks have a positive effect on corporate sustainability performance (**Tian et al., 2025**).

With increasing sustainability issues, there have been many more studies carried out in this subject. Previous literature has studied the environmental management, sustainable production, circular economy, ESGs, supply chain and clean energy technologies. Yet, there are still many interrelated and complex sustainability issues related to semiconductors that require further study (**Wang et al., 2023a**), but most previous reviews concentrated on particular aspects of the issue, rather than offering an overview of the field. Semiconductors play an increasingly important role in economic development and in modern society (**Ibrahim, 2026**). In return, Sustainability strategies have therefore become essential for the long-term growth of the semi-conductor industry (**Wang et al., 2023b**).

In order to bridge this gap, this research makes use of bibliometrics to analyze the development of sustainability studies within the semiconductor industry based on Scopus-indexed papers. In particular, the following topics will be covered: publication trends, influential authors, collaboration trends, intellectual base, and emerging themes. The study adds value to the body of environmental management literature and provides useful information for researchers and other interested parties in their efforts towards achieving sustainable transformation within the semiconductor industry.

The paper is structured as follows: Section 1 deals with introduction, section 2 covers the theoretical framework, section 3 covers the methodology, section 4 presents the results, section 5 contains the future research agenda, section 6 covers discussions and implications, and finally section 7 concludes the paper.

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2. Theoretical Background

2.1 Sustainability Challenges in the Semiconductor Industry

However, the semiconductor industry is an advanced but resource-intensive industry whose production activities are of great importance in ICT, electronics, AI, 5G, and the Internet of Things technologies (**Gatto and Nuta, 2026; Hafiz et al., 2025**). However, producing semiconductors demands the use of a considerable amount of energy, ultrapure water, chemicals, and critical raw materials, leading to the emergence of environmental challenges, such as greenhouse gas emissions, water shortage, pollution by hazardous wastes, and the depletion of natural resources (**Sandhu et al., 2025; Yin and Yang, 2025; Ouattara et al., 2026)**. This way, the sustainable balance between economy, environment, and society has become the key problem of the industry (**Shen and Tsai, 2022; Davies and Sankaralingam, 2025; Williams, 2025; Mishra et al., 2026**).

2.2 Energy Efficiency and Decarbonization

Energy efficiency and decarbonization are some of the current research trends due to the energy-intensity of semiconductor fabrication processes (**Pelcat, 2023**). Research highlights the need for carbon emission reduction, renewable energy, green hydrogen, and sustainable manufacturing (**Trapani et al., 2025; Zhang et al., 2025**). Decarbonization through life-cycle assessment, circular economy, and industry governance are recommended strategies to attain carbon neutrality (**Negi et al., 2026**). Carbon management has impacts on both environmental

and economic sustainability (**Huang & Chang, 2026; Ho et al., 2026; Chou et al., 2026)**, yet there are few viable solutions within the framework of fabrication processes (**Byeon et al., 2026; Tai et al., 2026**).

2.3 Environmental Management and Green Manufacturing

However, environmental management and green manufacturing have been deemed important to minimize ecological effects from the fabrication of semiconductor devices. The researches highlight pollution prevention, cleaner production, green innovation, and environmental management system (**Shen and Tsai, 2022; Fengyu et al., 2026**). There has been growing interest in sustainable product design, green VLSI designs, and environmentally sustainable manufacturing processes (**Harland et al., 2008; Chaudhary, 2025; Lin and Chen, 2025; Saranya, 2026**). In addition, there have been researches concerning the environmental effects of the manufacturing processes and the significance of smart manufacturing, recycling, and sustainable production systems (**Lee et al., 2022; Chien et al., 2024; Chang and Matsumoto, 2022; Sun et al., 2026; Kuo et al., 2025; Yeboah et al., 2024).**

2.4 ESG and Sustainability Governance

The issues of ESG and sustainability governance have become more prevalent in the semiconductor industry. The application of ESG helps achieve better environmental results and sustainability achievements (**Chen et al., 2025; Tseng et al., 2026; Chen and Liu, 2026**). Several studies reveal ongoing developments regarding ESG performance, especially in Taiwanese semiconductor industry (**Lin et al., 2026; Lu et al., 2025; Xiao et al., 2026**). The combination of AI and ESG increases sustainable innovation and competitiveness (**Chiu et al., 2025)**; however, due to lack of available information, sustainability assessment remains challenging for some organizations (**Yi, 2025; Lin et al., 2025**).

2.5 Circular Economy and Resource Efficiency

Circular economy approaches have become prominent in the semiconductor industry due to their focus on waste minimization, recycling, reuse, and resource efficiency (**Pan et al., 2024; Kim et al., 2026)**. The research has pointed out electronic waste upcycling, artificial intelligence (AI)-driven waste segregation, and circular business models as possible means of addressing the issue of resource scarcity and ecological concerns (**Paul et al., 2025; Dagwar et al., 2026; Hadj, 2025; Schröder et al., 2025**). Furthermore, it has been stressed that the manufacturing process efficiency should be increased (**Ghasemi et al., 2020; Ruberti, 2024; Park et al., 2025; Szávó, 2026**).

2.6 Sustainability Measurement and Performance

Furthermore, sustainability evaluation has been gaining more attention, and researches have considered ESG performance, carbon emissions, CSR, environmental disclosures, and sustainability reporting (**Hsu et al., 2011; Barik et al., 2025**). The findings indicate that sustainability has a positive impact on the company's performance, ecological efficiency, firm value, and risk reduction (**Lu et al., 2026; Ruberti, 2023; Li et al., 2026a, 2026b**). Moreover, green innovation contributes to the better ESG performance and the environment (**Wang et al., 2025**). Nevertheless, discrepancies between reporting standards and regulations still create difficulties in evaluating sustainability in the semiconductor industry (**Nagapurkar et al., 2024; Ma et al., 2026; Ang and Liao, 2026**).

3. Methodology

3.1 Research Design

The current study uses bibliometric and thematic analysis technique in investigating the development of sustainability research in the semiconductor industry. Bibliometric analysis is a quantitative tool that makes it possible to analyze the scientific works, citations, collaboration, and thematic developments in a specific research area. This process involves the use of statistical and mathematical approaches in the analysis of bibliographic information to detect trends and patterns in a research field or among various disciplines (**Donthu et al., 2021**). As compared to traditional review methods, bibliometric techniques help in gaining a much more objective and holistic view of the intellectual, social, and conceptual aspects of a research field. In this study, the tools used for

conducting performance, social structure, intellectual structure, and conceptual structure analyses include Biblioshiny and VOSviewer. Figure 1 shows the research process used in this study.

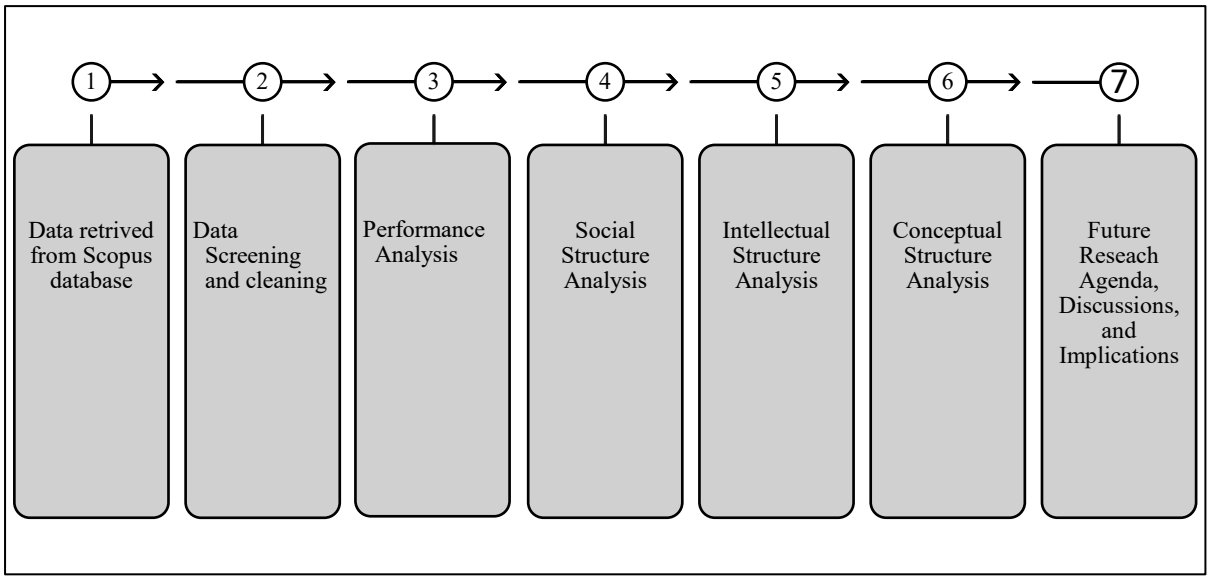


Figure 1. Research workflow adopted for the bibliometric and thematic analysis of sustainability research in the semiconductor industry.

3.2 Data Source and Search Strategy

Bibliographical data were extracted from the Scopus bibliographic database, which is well known for being one of the largest multidisciplinary bibliographic databases, and which is often used in bibliometrics research owing to its broad coverage of peer-reviewed journals and rich metadata.

In order to select research in the area of sustainability of the semiconductor industry, a search query containing three sets of keywords was used: (1) those related to semiconductors, (2) those related to the industry, and (3) those related to sustainability. The following search query was used:

[TITLE-ABS-KEY (**semiconductor* OR semi-conductor* OR "semi conductor" OR "semi conductors") AND TITLE-ABS-KEY (industry OR manufacturing OR sector**) AND TITLE-ABS-KEY (**sustainab* OR "environmental sustainability" OR ESG OR "environmental management" OR "energy efficiency" OR decarbon* OR "carbon neutrality" OR "sustainability reporting" OR "circular economy"**)]. In order to make sure the search is relevant and consistent, the following filters were used to narrow down the results: Publication years: 2000-2026; Language: English; Document Types: Articles & Review Articles. The categories of Energy, Environmental Science, and Business, Management and Accounting have been chosen for their multidisciplinary nature of sustainability research in the semiconductor industry. The restriction of the database to the chosen fields made the topic more relevant and helped to exclude technically-oriented sources. In this research, sources published from 2000 to 2026 were analyzed. 2000 was chosen as the beginning point since the issues of sustainability, environmental management, and corporate social responsibility received increasing attention in academic and business circles in the early years of the twenty-first century.

Data Screening and Cleaning

The retrieved database was extracted from Scopus using CSV format and underwent a data cleaning procedure before analysis. The data cleaning process entailed the elimination of duplicate records; checking of the publication details; author keywords standardization; and spelling and synonym standardization. For instance, the keyword variations like photocatalyst and photocatalysis were standardized if necessary to enhance the consistency during co-occurrence analysis. In addition, variations of semiconductor terms were considered in the

search strategy in order to retrieve all the relevant studies. The final database comprising 734 publications formed the basis for bibliometric analysis.

3.4 Bibliometric Analysis Tools

Two software tools that complement each other have been used; Bibliometrix/Biblioshiny and VOSviewer. Bibliometrix is an open-source R package that can conduct bibliometrics analysis, whereas Biblioshiny is a web graphical interface of conducting bibliometrics analysis (**Aria and Cuccurullo, 2017, 2026; Zupic, I. and Čater, T., 2015**). VOSviewer has been used to make bibliometric maps. This software is ideal for science mapping and network visualization (**Van Eck and Waltman, 2010**).

3.5 Analytical Framework

In line with the bibliometric framework suggested by **Donthu et al. (2021)**, the current research conducted the analyses in four different dimensions: performance analysis, social structure analysis, intellectual structure analysis, and conceptual structure analysis. The tools of biblioshiny and VOSviewer were used for the visualization and interpretation of the underlying structure of the research **(Aria and Cuccurullo, 2017, 2026; Van Eck and Waltman, 2010**). The performance analysis measures the productivity and impact of scientific research within the field (**Cobo et al., 2011; Ramos-Rodrígue and Ruíz-Navarro, 2004; Donthu et al., 2021**). Social structure analysis assesses the relationships between the authors, institutions, and countries in terms of collaboration in a particular research field. At the same time, intellectual structure analysis investigates the fundamental knowledge base and major contributors in a particular research field. It is carried out through author co-citation, source co-citation, and citation network analysis in order to reveal the intellectual foundation of the sustainability research within the semiconductor industry. Finally, conceptual structure analysis assesses the thematic structure and development of the research field.

4. Results and Discussion

4.1 Overview of the Dataset

The final set of papers included 734 papers from 235 sources and published from 2000 to 2026. There has been significant growth in the field, with an annual growth rate of 14.72% implying the increase in academic interest in sustainability in the field of semiconductors. The papers had an average age of 4.47 years and each paper received 46.52 citations on average, which means that the research is fairly impactful. The database included 127,158 cited references, which means that there is a large body of knowledge in the field.

Regarding the topics, there are 7,315 Keywords Plus and 2,758 Author Keywords, which implies a certain diversity of themes. In total there were 3,456 authors writing on the topic of sustainability and semiconductors, only 37 documents have single authors, thus implying that there is a culture of collaboration. The average number of co-authors for one document was 4.99 and international collaboration took place in 32.15% of all papers. Concerning the types of documents in the database, the main types were research articles (594 or 80.9%) and review articles (140 or 19.1%).

4.2 Performance Analysis

Based on the performance analysis, there has been significant progress made in the field of sustainability literature associated with the semiconductor industry especially since 2018 (see figure 2 below) due to more concern about environment sustainability, energy efficiency, decarbonization, and other ESG concerns. The publications sources that appeared to be dominant include **Sustainability (Switzerland), Journal of Cleaner Production,** and **ACS Sustainable Chemistry and Engineering** (see table I below). As for the author productivity, the most prolific authors were **Lu Wen-Min** and **Swain Basudev,** whereas **Chien Chen-Fu** was the author with the highest local citation count (see table II below).

China was at the forefront when it came to publishing and citations, whereas **Australia** showed citation prominence despite having fewer publications (as seen from Table III). In terms of institutions, **Kunming**

University of Science and Technology and **Arizona State University** were some of the prominent institutions (as seen from Table IV). The study of citation showed that the influential papers came from various disciplines such as environmental science, strategic management, renewable energy, and sustainable manufacturing, thus showing the multidisciplinary aspect of sustainability in the semiconductor industry (as seen from Table V).

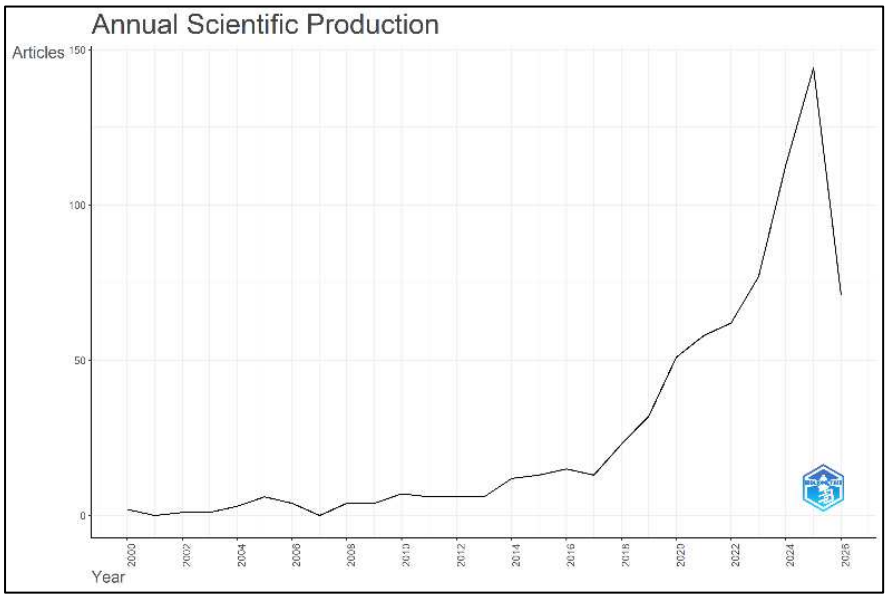


Figure 2. Annual Scientific Production from 2000–2026 till May [Source: Generated using Biblioshiny]

Table I. Top five Journals Publishing Sustainability Research in the Semiconductor Industry	
Sources	No. of Articles
SUSTAINABILITY (SWITZERLAND)	45
JOURNAL OF CLEANER PRODUCTION	32
ACS SUSTAINABLE CHEMISTRY AND ENGINEERING	29
CHEMICAL ENGINEERING JOURNAL	24
SOLAR ENERGY	21

Table II. Most productive and most influential authors in sustainability research related to the semiconductor industry.			
Author	Articles	Author	Local Citations
LU, WEN-MIN	6	CHIEN, CHEN-FU	20
SWAIN, BASUDEV	6	CAI, HANYING	19
CHANIAGO, YUS DONALD	5	CHEN, XIAOWEN	19
LEE, CHAN GI	5	HUANG, NAN	19
LEE, MOONYONG	5	WANG, QI	19

Table III. Top five most productive and most influential countries in sustainability research related to the semiconductor industry.			
Country	No. of documents	Country	Total Citations

CHINA	1183	CHINA	6592
INDIA	372	AUSTRALIA	5745
USA	344	USA	4502
SOUTH KOREA	304	INDIA	3450
UK	132	KOREA	2160

Table IV. Top productive institutions in sustainability research related to the semiconductor industry.

Affiliation	Articles
KUNMING UNIVERSITY OF SCIENCE AND TECHNOLOGY	32
ARIZONA STATE UNIVERSITY	28
FUZHOU UNIVERSITY	26
THE HONG KONG POLYTECHNIC UNIVERSITY	25
SHENZHEN UNIVERSITY	23
TSINGHUA UNIVERSITY	23
YEUNGNAM UNIVERSITY	23

Table V. Top cited documents in sustainability research related to the semiconductor industry

Document	Total Citations	Average Yearly Citations
Chong et al. (2010)	4981	293
Hatch and Dyer (2004)	1082	47
Peng et al. (2013)	686	49
Lin et al. (2023)	621	155.2
Ager et al. (2015)	569	47.4

4.3 Social Structure Analysis

4.3.1. Country Collaboration Network Analysis

Figure 3 shows the network map of country collaboration in sustainability studies in relation to the semiconductor industry. The network shows how there is a lot of cooperation across countries in the study of science in the semiconductor industry. Countries such as **China, USA, India, South Korea,** and **UK** play prominent roles in this network due to their contributions to both scientific productions and collaborations in research. The interconnectedness of these countries highlights the interdisciplinary aspect of sustainability issues in the semiconductor industry. The collaboration clusters also suggest the existence of research groups based on regions and themes.

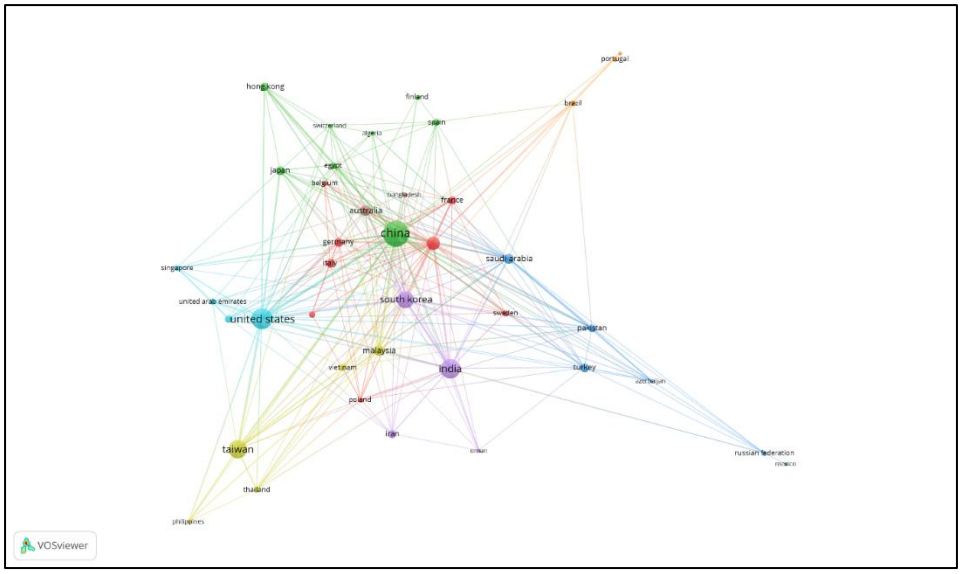


Figure 3. Country collaboration network in sustainability research related to the semiconductor industry [Source: Generated using VOSviewer]

4.3.2. Institution Collaboration Network Analysis

The institution collaboration network in the sustainability area for the semiconductor industry is shown in Figure 4. There is a relatively fragmented structure of the network with several small clusters having minimal inter-institutional connections. Hence, it can be seen that collaborative efforts are mainly carried out by individual research teams and not on a global, integrated level. Another interesting finding was the dominance of Asian institutions, including Chinese and Korean organizations, which coincides with the geographic distribution of the semiconductor industry and sustainability technologies development in the Asia-Pacific region.

There were institutions representing such areas as environmental sciences, industrial engineering, materials science and sustainable engineering among those participating in the collaboration network. It proves once more the interdisciplinary character of the research and the importance of the Asia-Pacific region in terms of its contribution to the development of sustainability studies in relation to the semiconductor industry.

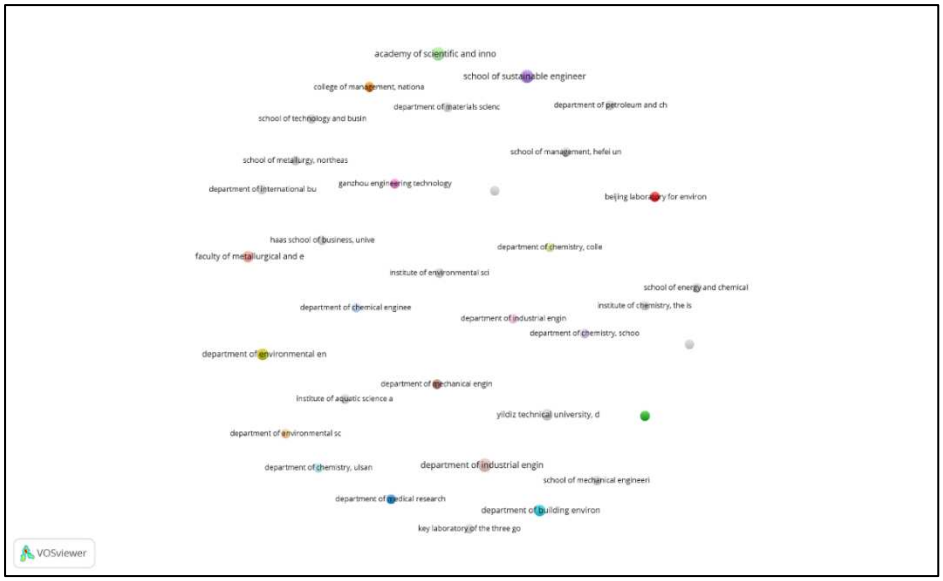


Figure 4. Institution collaboration network in sustainability research related to the semiconductor industry [Source: Generated using VOSviewer]

4.3.3. Author Collaboration Network Analysis

Figure 5 presents the author collaboration network on sustainability in the research of the semiconductor industry. The network consists of a number of collaboration clusters demonstrating that there are various author collaboration communities. **Lu Wen-Min, Swain Basudev,** and **Chaniago Yus Donald** are among the authors who are highly represented in the network and who actively collaborate in research. At the same time, a number of authors, such as **Chou Jui-Sheng, Dong Cheng-Di, Ma Wenhui,** and **Lee Hyunseop**, represent collaboration clusters, demonstrating active collaboration in the research within specific thematic areas. The existence of a number of collaboration clusters shows that sustainability research in the semiconductor industry includes the research carried out by various research communities engaged in different issues associated with environmental management, sustainable manufacturing processes, energy efficiency, and technologies. The network is quite fragmented despite the existence of several collaboration clusters, because many authors are located on its margin and do not have many inter-cluster links.

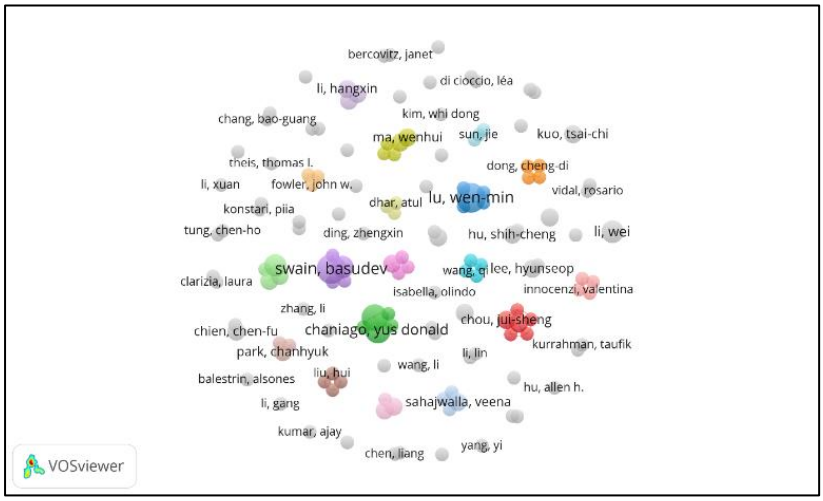


Figure 5. Author collaboration network in sustainability research related to the semiconductor industry. [Source: Generated using VOSviewer]

4.4 Intellectual Structure Analysis

4.4.1. Author Co-citation Analysis

The author co-citation map is shown in Figure 6, depicting the intellectual structure of sustainability studies in the semiconductor industry. With Minimum number of citations of an author maintained at forty, a total of 39 authors become eligible for inclusion. It is noteworthy to observe that the network comprises of several clustered nodes signifying the fact that the field is founded on several but interlinked knowledge streams. Authors like **Wang X., Wang Y., Wang J., Zhang X.,** and **Liu Y.** emerge as key players.

The presence of distinct clusters also serves as an indication of the existence of distinct knowledge fields within the literature. Though every cluster denotes a particular stream of research, the numerous connections between different clusters reflect the highly integrated intellectual nature of this research field. These connections between clusters reveal the highly developed nature of the knowledge base involving multiple disciplines such as environmental sustainability, energy systems, sustainable manufacturing, and material sciences. All in all, the results show the multidisciplinary and highly developed nature of the research field of sustainability in the semiconductor industry. In comparison to your author collaboration network, the co-citation network is much denser, which is quite a positive result.

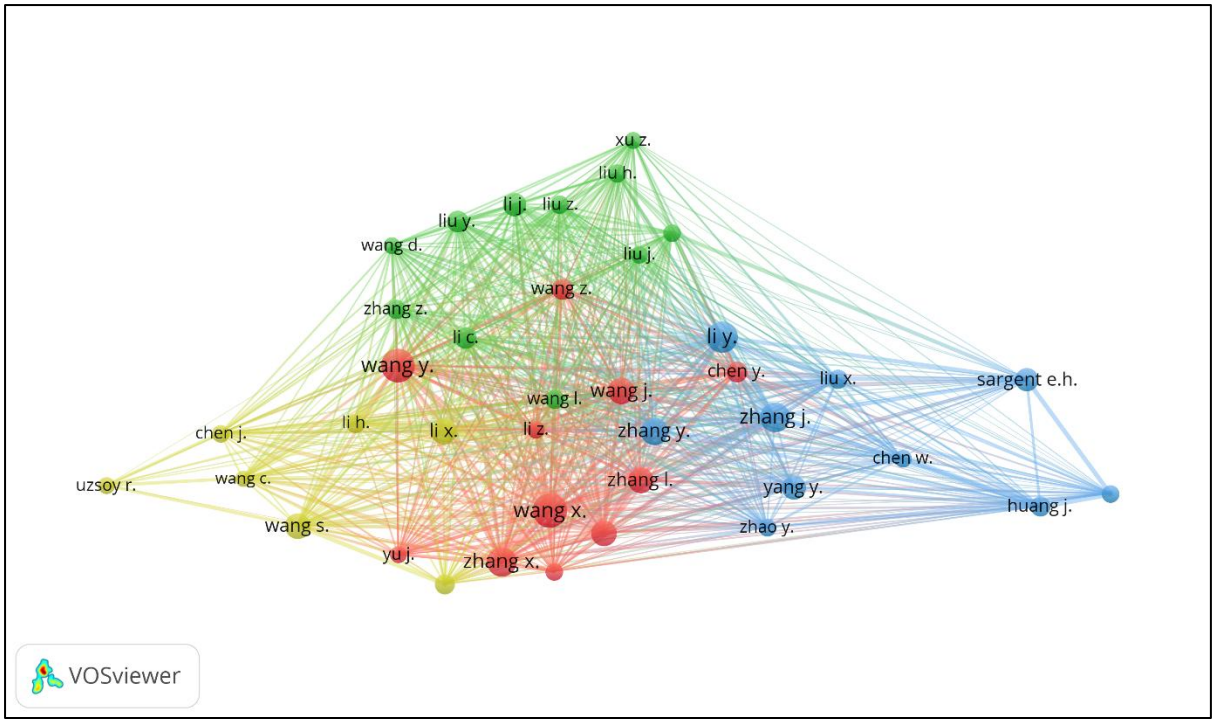


Figure 6. Author co-citation network in sustainability research related to the semiconductor industry. [Source: Generated using VOSviewer]

4.4.2. Source Co-citation Analysis

Figure 7 represents the source co-citation network, representing the intellectual foundation of sustainability research in the semiconductor industry. Following removal of sources having less than 100 citations, there are 62 sources remaining. There are several clusters formed within the network, representing the multidisciplinarity of the domain. Journals like **Journal of Cleaner Production, Sustainability, Environmental Science & Technology, Chemical Engineering Journal, Advanced Materials,** and **Energy & Environmental Science** form the core of the network, implying their significant impact on the development of knowledge. The clustering shows the following knowledge domains: sustainable manufacturing and environmental management (green cluster), advanced materials and energy technologies (red cluster), chemical and environmental engineering (blue cluster), and sustainable chemistry and educational research (yellow cluster). It is evident that all clusters have very tight connections, implying a high level of intellectual integration of the knowledge in the field of sustainability in the semiconductor industry.

The following research domains are reflected in the cluster structure: sustainability and environmental management, energy technologies, advanced materials, and chemical engineering.

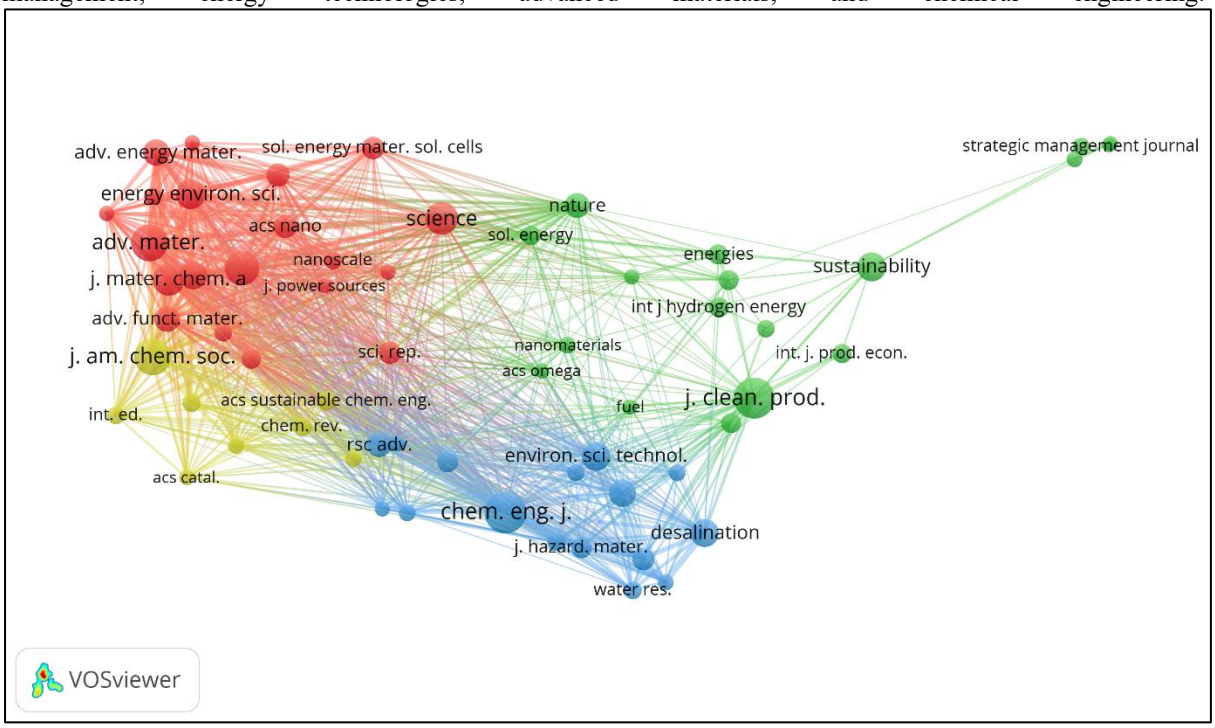


Figure 7. Source co-citation network in sustainability research related to the semiconductor industry [Source: Generated using VOSviewer]

4.4.1. Citation Network Visualization

Figure 8 below shows the citation network of some of the influential publications within the area of sustainability studies associated with the semiconductor industry. Having excluded those publications that do not have at least a hundred citations, 68 remain. The citation network highlights many high impact publications that have greatly influenced the development of the field. **Chong (2010)** is the leading influential publication in the network, followed by **Hatch (2004), Peng (2013),** and **Lin (2023)**. The different sizes of the nodes are indicative of the impact of citation, meaning that the network incorporates contributions from both influential older works as well as recent publications that have had a great impact in shaping the evolution of the literature. The presence of influential older and recent publications indicates that the field evolves based on the integration of sustainability

theory with emerging clean technologies and energy efficient industrial practices.

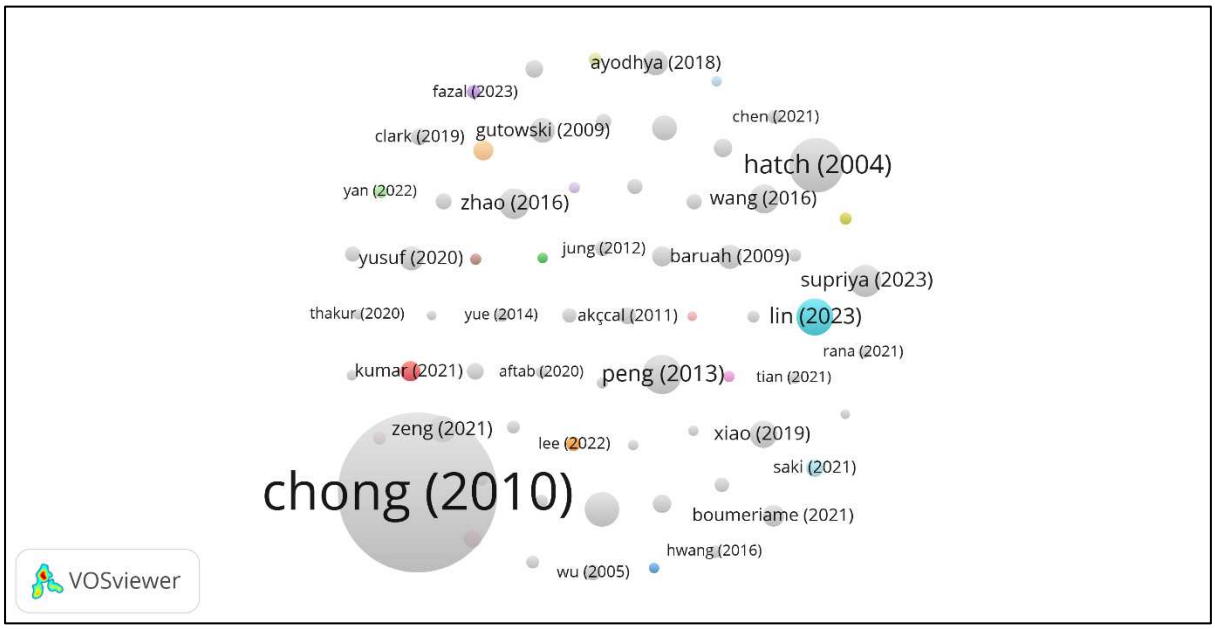


Figure 8. Citation network of influential publications in sustainability research related to the semiconductor industry [Source: Generated using VOSviewer]

4.4 Conceptual Structure Analysis

4.5.1. Keyword Co-occurrence Analysis

Insight regarding the conceptual structure of sustainability research conducted in the semiconductor industry is revealed through the keyword co-occurrence network (Figure 9). The minimum number of occurrences for each keyword has been maintained at five, after which 44 qualify for inclusion. The three most dominating keywords are those relating to sustainability, semiconductor, and semiconductor industry, which are considered to be the key areas of research.

The major clusters identified in the thematic analysis includes the the **red cluster** that focus on sustainable semiconductor manufacturing, which includes terms such as **sustainable development, semiconductor manufacturing, decarbonization,** and **semiconductor supply chain.** It can be stated that this cluster is a representation of growing academic interest in minimizing the environmental effects and improving the sustainability performance within the semiconductor industry value chain.

Another important cluster is the **orange cluster**, which is related to the **circular economy and recycling of semiconductors, e-waste, supply chain management,** and **semiconductor wastewater**, highlighting research on resource recovery, waste minimization, and circular production practices. The prominence of circular economy-related terms suggests a growing emphasis on material efficiency and sustainable resource management.

Mainly, the **green cluster and the blue cluster** refer to technology-based sustainability research related to **waste-water treatment, ZnO, nanocomposites, photocatalysis, hydrogen generation, water splitting,** and **solar energy**. These themes indicate strong interest in advanced semiconductor materials and clean-energy technologies for environmental applications.

In general, the network shows that sustainability research within the semiconductor industry is developing through the use of sustainable manufacturing, circular economy concepts, environmental management, and technology development. The high number of connections between keywords implies that there is a multidisciplinary knowledge foundation for sustainable development in the semiconductor industry.

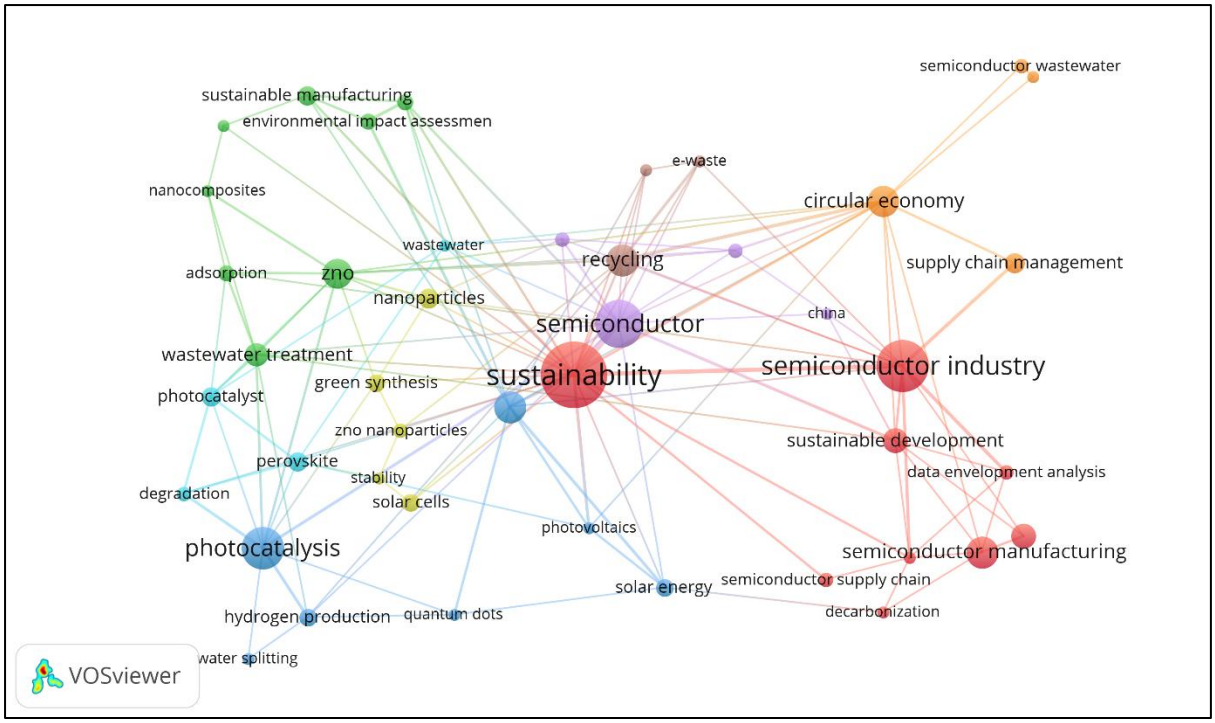


Figure 9. Keyword co-occurrence network illustrating the conceptual structure of sustainability research in the semiconductor industry. [Source: Generated using VOSviewer]

4.5.2. Keyword Density Visualization

Figure 10 displays the keyword density chart of sustainability research in the semiconductor industry. On the keyword density map, warm colors (yellow) symbolize very frequent and interrelated keywords, while cool colors (green and blue) denote less frequent themes. It can be seen that the keyword "**sustainability**" is the most prevalent one and lies at the heart of the research cluster because it has high associations with the keywords "**semiconductor**," "**semiconductor industry**," "**recycling**," and "**sustainable development**."

The other prominent cluster is centered around the keywords "**semiconductor industry**" and "**semiconductor manufacturing**" because the increasing number of scientific publications focuses on sustainable manufacturing processes, environmental performance, and decarbonization of semiconductors production. Related keywords such as "**supply chain management**," "**semiconductor supply chain**," and "**circular economy**" show increasing research interest in sustainability along the entire semiconductor value chain.

Furthermore, the figure shows another technological-environmental cluster that includes terms like "**photocatalysis**," "**ZnO**," "**nanoparticles**," "**wastewater treatment**," and "**perovskite**." Such a cluster shows a lot of attention given to the studies connected with advanced semiconductor materials used in the field of environmental remediation, renewable energy production, and pollution control. In addition, key terms like "**solar cells**," "**photovoltaics**," "**hydrogen production**," and "**water splitting**" show the interconnection between the application of semiconductor technology and the goals of clean energy.

In summary, it can be stated that there are three main clusters of research interest identified by the density map: (i) sustainability and sustainable development in semiconductor industry; (ii) circular economy and resource recovery; and (iii) semiconductor materials and technologies in relation to environmental and renewable energy applications. Thus, these results prove the gradual change from traditional issues in manufacturing towards sustainability and circular economy in the field of semiconductors.

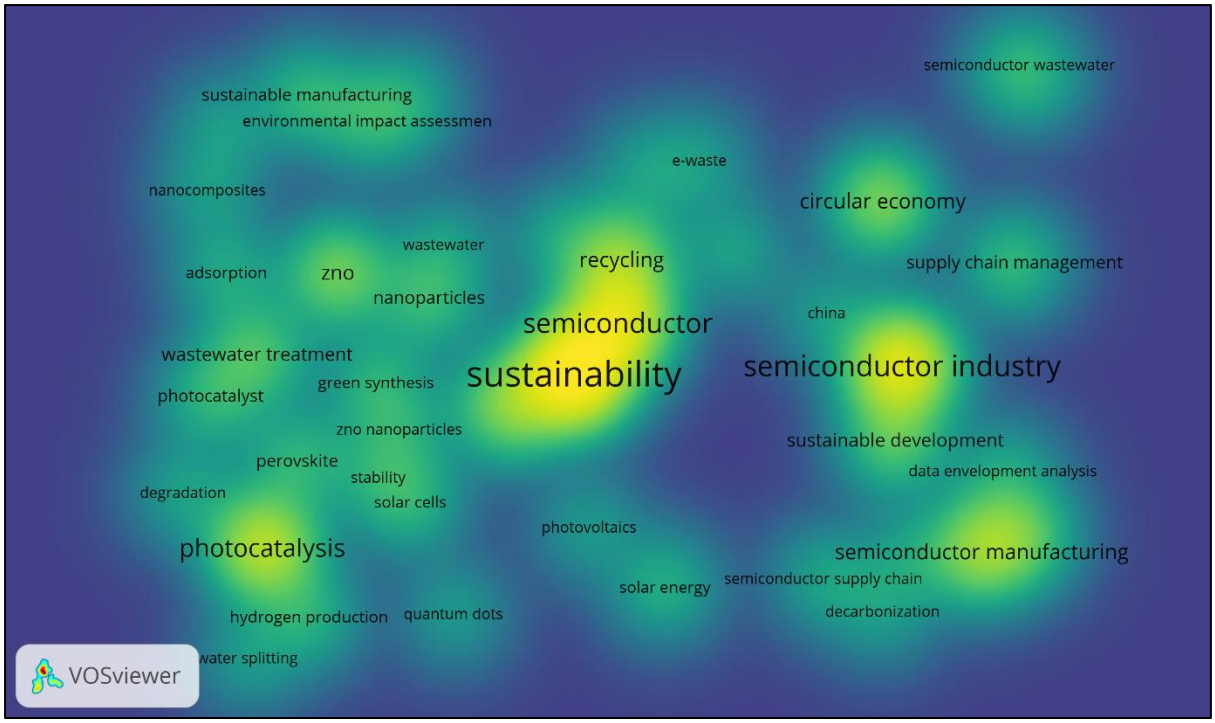


Figure 10. Keyword density visualization of sustainability-related research in the semiconductor industry. [Source: Generated using VOSviewer]

4.5.3. Trend Topics Analysis

Figure 11 depicts the chronological development of themes in sustainability-associated semiconductor research between the years 2008 and 2026. It is seen that there has been a transition from themes dealing with "**strategic planning," "customer satisfaction," "photovoltaic effects,"** and "**environmental burdens"** to more sustainability-based and technology-based themes.

During the years 2014 and 2020, research on themes such as "**renewable energy resources," "waste treatment," "photovoltaic cells," "manufacturing processes," "electronic equipment**," and "**environmental management"** emerged, signifying rising awareness about the need for environmental efficiency. In recent years, themes related to "**energy efficiency," "sustainability," "sustainable development," "semiconductor industry,"** and "**semiconductor device manufacturing"** have become very prominent, pointing towards increased focus on sustainable manufacturing in the industry.

New themes which are coming up since 2022 are "**circular economy," "layered semiconductors," "hydrogen evolution reaction," "risk assessment,"** and "**performance**." It shows that research in this area is shifting towards more sustainable production processes, development of semiconductors, use of renewable sources of energy, and performance assessment. From the trend analysis, it can be seen that the area of focus has shifted from operations to sustainability.

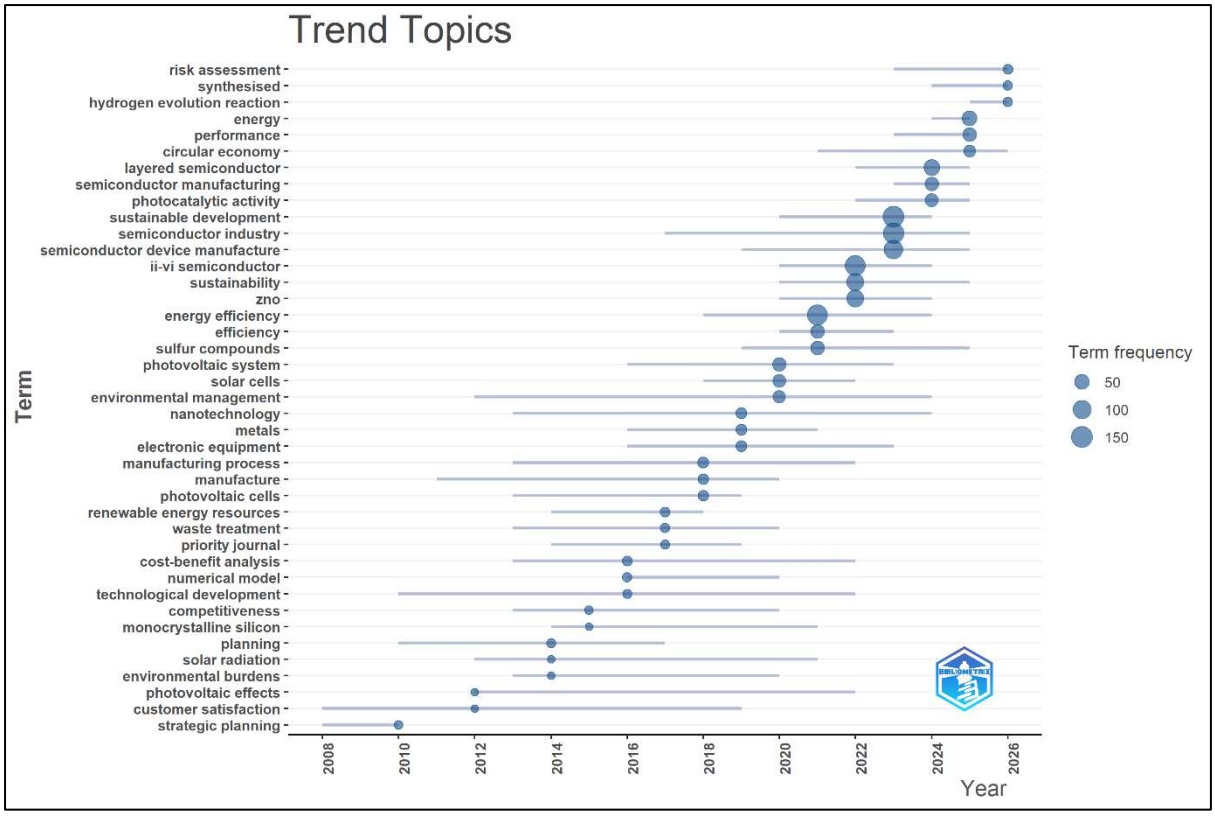


Figure 11. Trend topics analysis showing the evolution of sustainability-related research themes in the semiconductor industry (2008–2026) [Source: Generated using Biblioshiny].

5. Future Research Agenda

From the results of the bibliometric analysis, a number of emerging trends have been identified which are very likely to provide interesting research directions for the study of sustainability within the semiconductor industry.

For example, future research should consider the **concept of circular economy** in relation to semiconductor production. While issues such as recycling, e-waste management, and resource recovery have attracted considerable attention, there is a lack of research related to closed loop production systems and material circularity.

Secondly, the increasing emphasis on **decarbonization and energy efficiency** implies the need for researches that look into the issue of carbon-neutral manufacturing practices. In particular, the future research may explore the incorporation of renewable energy, carbon accounting, life cycle emissions, and net zero-manufacturing in semiconductor manufacturing.

Thirdly, the development of **sustainable supply chains** provides grounds for studies in supplier sustainability, supply chain resilience, environmental risk management, and ESG incorporation. Considering that the semiconductor industry is global, cross-country studies in sustainable supply chain management would be especially useful.

Lastly, the technologies mentioned in the theme of semiconductor technology, such as **photocatalysis, hydrogen production, perovskites, ZnO,** and **advanced semiconductor materials** imply the need for interdisciplinary studies on the link between scientific breakthroughs and environmental sustainability outcomes.

Furthermore, the rise of the importance of **artificial intelligence and digitalization** implies that future research needs to look at the potential of AI, big data, and smart manufacturing to monitor, optimize, predict and support decision-making about the sustainability, energy use, and maintenance in semiconductor production.

The little overlap between the most prolific and most cited researchers indicates that the field is rather diverse with contributions coming from several streams of research, such as sustainability management, environmental performance, energy systems, and semiconductor technology.

6. Discussion and Implications

6.1 Discussions

It is clear that the number of research publications dealing with sustainable aspects in the semiconductor industry has been increasing. Scholars are becoming more interested in sustainability, energy-efficient operations, circular economy, and sustainable manufacturing in semiconductors (**Bardon et al., 2020; Gocyla et al., 2026**).

Cooperation networks show the need to develop connections between countries, organizations, and researchers in this field. It is crucial for scholars and firms to foster cooperation between academic and business sectors because it would facilitate the involvement of semiconductor innovations in the achievement of SDGs (**Hsieh et al., 2023**). Additionally, achieving sustainable development in the semiconductors sector implies collaboration within the industry rather than actions taken by separate companies (**Yoo and Cho, 2024**).

The development of topics like ESG, decarbonization, circular economy, and sustainable supply chains is another proof of changing times in this field (**Chen et al., 2025; Byeon et al., 2025**). Nevertheless, there is still very little academic research devoted to sustainable management in the semiconductor industry (**Yoo and Cho, 2024**).

Nevertheless, this work also has some weaknesses. First of all, the analysis was carried out with the help of the Scopus database only and took into account English papers only, which means that the study might have missed some valuable publications published elsewhere. Furthermore, the analysis of thematic evolution and construction of conceptual maps was impossible because of the limitations of the dataset used. Future works will probably take into consideration several sources, conduct longitudinal analysis of themes, and explore new trends such as artificial intelligence, digitalization, carbon neutrality, and circular economy.

6.2 Theoretical Implications

The present research makes an important contribution to the body of sustainability and environmental management literature in terms of understanding of the structure of intellectual, conceptual, and social networks of sustainability studies in the semiconductor industry. In this regard, the results prove that this sphere has already shifted from being technologically focused to being multidisciplinary and including sustainability, circular economy, ESG, decarbonization, and sustainable supply chain management. Combining performance analysis and science mapping methodology, this study advances our understanding of sustainable industrial development, indicating the increasing intersection between environmental management and semiconductor studies. At the same time, the revealed topics and knowledge structures can be used as the basis for further theorizing of sustainability management in high-technology industries.

6.3 Practical Implications

The practical implications of the results of this research for both practitioners and policymakers are numerous. The emergence of such themes as sustainability, energy efficiency, circular economy, ESG, and sustainable supply chains is an indicator of areas where semiconductor companies should focus on to enhance their environmental performance and sustainability. Collaboration studies additionally suggest that partnership between industries, academia, and policymakers can be used as a tool to facilitate innovation and sustainability. Moreover, the growing relevance of decarbonization, resource efficiency, and ESG practices implies that organizations should consider sustainability issues when making strategic decisions. Policymakers will benefit from these findings by using them to design policies that will help to build a more sustainable and resilient semiconductor industry.

7. Conclusion

This study offers a bibliometric analysis of studies related to sustainability in the semiconductor industry using a total of 734 scientific papers published within the period of 2000 to 2026 as indexed by Scopus. This study utilized Biblioshiny and VOSviewer software for its analyses.The findings indicate a significant growth in research output,

China, India, and the US as some of the primary researchers in this regard. Sustainability, manufacturing of semiconductors, circular economy, energy efficiency, recycling, and sustainable development were found to be among the most dominant research topics. Decarbonization, supply chain sustainability, and artificial intelligence are some of the emerging research topics that may provide promising areas for further investigation. Collaboration networks imply the existence of several research communities, although more international and interorganizational collaboration is still needed.

On the whole, this work presents a systematic understanding of the theoretical and social background of the sustainability research in the semiconductor industry.

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