Can green finance facilitate the industry 5.0 transition to achieve sustainability? A systematic review with future research directions

Abstract

Most of the world's rising carbon emission results from industrial activities. Previous industrial revolutions did not put much thought into safeguarding the natural world. Governments worldwide have been continuously implementing regulations and policies for the mitigation of climate change to promote sustainable development. To achieve decarbonization, the climate change discussion is merged with Industry 5.0 (I5.0) where green finance (GF) plays a crucial role. This technological metamorphosis of transition from Industry 4.0 (I4.0) to I5.0 will affect humans and their society. I5.0 forms a symbiotic relationship with different aspects of Society 5.0 (S5.0) such as social (human–machine centricity), ecological (zero emissions), and technological (green innovations). Thus, the I5.0 transition prioritizes greening the economy in pursuit of achieving S5.0. Through a systematic review of 196 articles, this research study concisely summarizes the rapidly expanding body of information. The research domain gave six major themes: Green Innovations (GI), Green Manufacturing Practices (GMP), Circular Economy (CE), Green Supply Chain Management (GSCM), Emerging Economies, and Net Zero Economy (NZE). Finally, a framework has been provided that illustrates the supporting role of GF for the I5.0 transition eventually followed by S5.0. This study provides an overview of these themes with their propositions and future research directions. The present study addresses the knowledge gap by providing valuable contributions to the burgeoning research domain of I5.0 and GF. Moreover, it aims to garner the attention of different stakeholders to integrate these two concepts of research to attain the goal of sustainable development.

Keywords: Green Finance, Society 5.0, Green Innovations, Circular Economy, Sustainable Development, Industry 5.0.

1. Introduction

The Paris Climate Agreement of 2015 aims to limit global warming to well below 2 degrees Celsius, and preferably 1.5 degrees Celsius, relative to preindustrial levels. Significant attempts have been made to meet this goal by 2030, and governments have been working for an early peak in carbon emissions and eventual carbon neutrality by 2050 (IEA, 2021a, 2021b). Humans have made progress in history by recognising the use and potential of 'technology' as a factor of production. The majority of the significant advancements and innovations of the past several centuries were made possible by the role technology played in earlier industrial revolutions. GF can address the environmental challenges of the industrial sector by promoting sustainability. It will direct investments towards the adoption of technologies, process setup, enabling infrastructure and finally the use of sustainable practices for mitigating climate change (UNEP, 2022). GF projects help in the clean energy transition by reducing greenhouse gas emissions from the energy-intensive operations of several industries (World Bank Group, 2019).

The first industrial revolution during the 1780s, namely, Industry 1.0 (I1.0), was based upon the role of 'mechanisation' propelled by fossil fuels and steam engines. This was followed by the second industrial revolution that began around the 1870s, Industry 2.0 (I2.0), which was based upon ‘mass production through electrification’. The 1960s saw Industry 3.0 (I3.0), which brought advancements in 'automated production' through computers and electronic devices. The term "digitalisation" was used in the early 2000s to describe the usage of digitally advanced technologies such as the “Internet of Things” (IoT), “Cyber-Physical Systems” (CPS), “Cloud Computing” (CC), “Big Data Analytics” (BDA), and “Additive Manufacturing” (AM). to usher in Industry 4.0 (I4.0) (Ghobakhloo, 2020; Lasi et al., 2014; Madsen & Berg, 2021; Xu et al., 2018). Industry 5.0 (I5.0) represents a new era in the industrial revolution centred on "personalization via green manufacturing," which incorporates a cyber-physical cognitive system. The emergence of globalization and its subsequent impact on competitiveness has compelled businesses to transition towards the digital realm, wherein technologies facilitated by Industry 5.0 assume a progressively significant role (Das et al., 2023). I4.0 and I5.0 involve the use of technologies and data analytics along with automation to optimize the industrial processes for energy-efficient technologies and intelligent manufacturing systems that can help in resource efficiency and reduce energy consumption. GF investments towards these technologies can help to reduce costs and environmental sustainability (Ghobakhloo et al., 2022). Therefore, industries should take into account environmental factors while making any investment. In this way, they can identify, mitigate and reduce the risks associated with their operations.

Various studies (refer to table 1) have discussed and touched upon many aspects of I4.0 and I5.0. However, the importance of GF was found to be missing in the available literature for achieving environmental sustainability when the transition to I5.0 takes place. Thus, this lack of scholarly discussion has been the focus of this present study to explore this research domain through thematic clusters and identify possible future research directions.

Table 1. Previous literature studies on I4.0/I5.0

No.	Source	Methodology	Research outcome
1	Alves et al. (2023)	Meta-analysis	Investigate the significance of I5.0 technologies
3	Hein-Pensel et al. (2023)	SLR	Framework for measuring the progress of digital transition
4	Moosbrugger et al. (2022)	SLR	Study talks about what I5.0 is all about
5	Mourtzis et al. (2022)	BA	The importance of I5.0 to ongoing social trends and needs
6	Gürdür Broo et al. (2022)	SLR	Significance of I4.0 in engineering education, and major obstacles
7	Madsen & Berg (2021)	BA	Advent of the I5.0
8	Aslam et al. (2020)	IR	Accommodate the necessities of the IoT and I5.0
9	Rosa et al. (2020)	SLR	Linkages between the CE and the I4.0
10	Nahavandi (2019)	Case study	Manufacturing's industry response to I5.0
11	Present study	IR	Role of GF for I5.0 transition for attaining sustainability
	Note: SLR refers to Systematic Literature Review, IR implies Integrated Review, and BA stands for Bibliometric Analysis		

The present study is important because the I5.0 transition will invest in cleaner and net-zero technologies that will be deployed in low carbon industries so that our cities, societies, and the modern world where we live are being protected from the devastating impact of climate change. I5.0 will ensure zero emissions by making use of greener innovations. I5.0 places strong emphasis on the role of humans in smart factories, which is the main base for sustainability-focused development. Apart from the implementation of I5.0 technologies in sustainable production and CE, there is a wide research gap present in relation to how GF can help to facilitate the I5.0 transition to achieve sustainability. However, Fraga-Lamas et al. (2021) have identified the role of green IoT as a key enabler for sustainable transition in the digital era by applying the case of I5.0. Ghobakhloo et al. (2022) have identified the contribution of I5.0 technologies that helps to move ahead from the profit-centric approach and to motivate the SDGs through a human-centric, resilience and socio-environment friendly approach. The study has provided a roadmap that integrates the intention of I5.0 for sustainable development functions. While there is an increase in the number of studies on the importance and adoption of I5.0, there are huge and certain gaps in terms of the theoretical, practical and policy implications of I5.0 technologies in the context of GF and sustainability. Apart from the lack of literature in I5.0 that integrates with the GF context, the gap is concerned with the information that GF plays a vital role in the advancement of the fifth industrial revolution that certainly improves sustainability and CE practices in the manufacturing and production process. Therefore, certain knowledge with respect to the relationship between GF and I5.0 becomes significantly important. Thus, the present study aims to answer the following identified research questions.

RQ1: What has been the publication trend, along with their top publication journals, most cited authors, top countries in terms of publications, major keywords, and top cited articles in this research domain?
RQ2: What has been the thematic development of the major research clusters in this area?
RQ3: What are the potential future research directions in this domain?

The rest of the present study is structured as follows: Section 2 deals with the background and literature review, section 3 mentions the research design methodology, and section 4 presents the data interpretation through bibliometric analysis. Section 5 discusses the emerging research themes, section 6 discusses the research findings, section 7 discusses the theoretical, practical and policy implications of the study, and finally, section 8 discusses the conclusion and limitations of the study.

2. Literature review

I5.0 is the ongoing industrial evolution that seeks to promote a sustainable and efficient future. Therefore, the need for GF solutions will become more critical to support this I5.0 transition. If policy incentives are given to businesses for the adoption of environmentally friendly and sustainable practices, then GF can mediate the I5.0 transition in a much better way. Various GF instruments (such as green bonds, sustainability-linked bonds, ESG investments, etc.) can push for the establishment of smart factories, the use of sustainable materials, energy-efficient machinery and increased use of renewable energy adoption. Therefore, GF can emerge as one of the key drivers of the I5.0 transition by providing much-needed capital support to companies for technological advancement and the integration of sustainable supply chains and by pushing for greener innovations.

I5.0 advocates believe that future industry vision should be based upon the principles of protecting the environment and S5.0 through metrics of sustainability. European Commission (2021) considers that I5.0 is a move beyond manufacturing by encompassing the collaborative vision of human-robot for S5.0. The commission also considers that I5.0 is not another chronological continuation phase of I4.0, but in fact, it merely complements the I4.0 paradigm through the socioenvironmental dimension. Sindhwani et al. (2022) explained that I5.0 promotes smart business ecosystems through the bioeconomy and resource efficiency.

There is significantly large availability of research literature on I4.0, which provides enough information on how it can add to sustainable development in ways such as sustainable energy (Ghobakhloo & Fathi, 2021), smart cities (Sharma & Arya, 2022), sustainable manufacturing (Ching et al., 2022), and smart waste management systems (Fatimah et al., 2020). Research scholars have stressed that while I4.0 is primarily 'technology driven' and I5.0 is mostly 'value driven'. Nevertheless, both industrial revolutions complement each other, and their coexistence can provide solutions to the many ongoing problems that have been impacting environmental sustainability. I4.0 comprises integrating the manufacturing process with newer technologies and innovations for automation. However, in this process, the role of humans has been ignored. I5.0 aims to bring out the balance by making use of human robot collaboration in this ongoing digital transformation (Alves et al., 2023; Aslam et al., 2020; Grabowska et al., 2022; Madsen & Berg, 2021; Nahavandi, 2019).

I5.0 has recognized that although I4.0 stresses digitalization and increased process efficiency, it fails to address the issue of sustainability and social equity. Thus, societal goals have to go beyond 'just jobs and profit growth', but industries should become resilient by placing more importance on workers' wellbeing and placing the production process within the 'permissible limits of the planet'. Thus, I5.0 ensures that the focus has shifted from 'shareholder value' to 'stakeholder value' where the industry's contribution to society also counts (Grabowska et al., 2022; Madsen & Berg, 2021).

The I5.0 design framework ensures that industries realize their true potential when sustainability and competitiveness are integrated. It involves human-centric transition pathways through the role of technology that leads to environmental sustainability, well-being and resilience. This I5.0 has its foundation built upon the I4.0 IoT technologies and makes use of artificial intelligence (AI) data whose insights serve the purpose of making value chains even more efficient. The ability to cope with the increased uncertainties and faster adaptation to the changing environment helps I5.0 strike the balance between machines and humans through its resilience. This resilient nature of I5.0 also bolsters a symbiotic relationship between man and machines by enhanced productivity, better quality jobs and a human-centric working environment. This not only helps in creating smart factories and smart workforces but also realizes the ultimate goal of S5.0.

Firms have been taking steps towards their commitment to reduce fossil fuel consumption and at the same time making a transition to cleaner energy technologies. Moreover, investors and regulatory bodies have emphasized reducing carbon emissions to lower their impact and burden on the continuously worsening environment. The environmental impact needs immediate attention through newer sources of energy adoption and raw materials to reduce waste generation. This objective of involving 'human touch' in the digital transformation era emphasizes the triple helix model of sustainable development (Environment, Social and Governance), which will be enabled by technology. I5.0 can help in making the transition from just 'profit-centric' production to 'human-centric' production, which promotes environmental sustainability and "sustainable development goals" (SDGs) for the end goal of S5.0 (Ghobakhloo et al., 2022). Finally, I5.0 has to act as the growth driver for the realization of SDGs through the implementation of disruptive technologies to achieve the goal of S5.0

(Huang et al., 2022; Kasinathan et al., 2022; Mourtzis et al., 2022). The coexistence of I5.0 and S5.0 will ensure human well-being and sustainability (refer to figure 1).

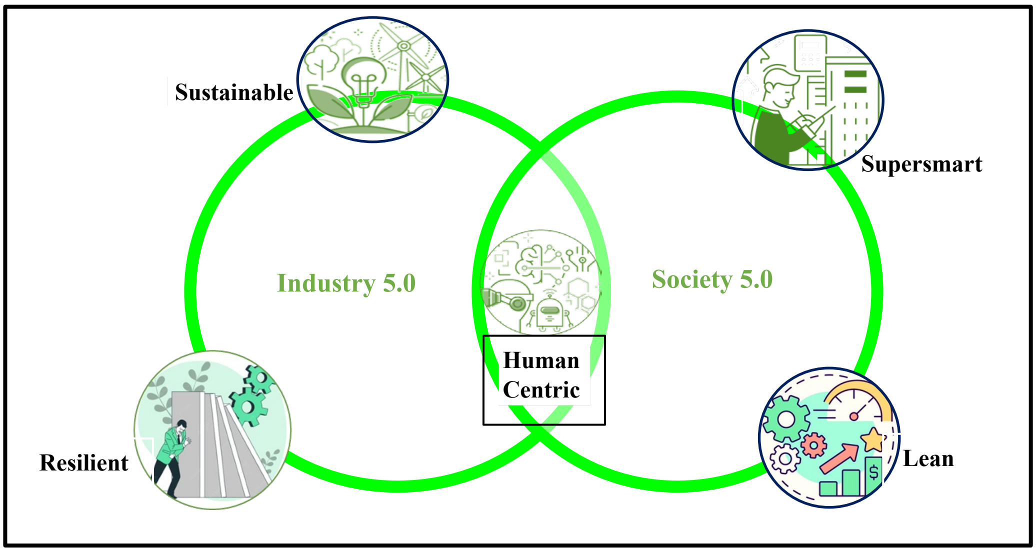

Figure 1. Co-existence of I5.0 and S5.0, Adapted from European Commission (2021)

Assembling

Identification

Domain: I4.0/I5.0 and Green Finance

Research Question (RQ):

RQ1: What has been the publication trend, along with their top publication journals, most cited authors, top countries in terms of publications, major keywords, and top cited articles in this research domain?

RQ2: What has been the thematic development of the major research clusters in this area?

RQ3: What can be the potential future research directions in this domain?

Source Type: Peer-reviewed research, **Source Quality:** Scopus

↓

Acquisition

Search Period: 2012 to 2022

Search Keywords: (“Industry 4.0” OR “Industry 5.0” OR “Industrial Revolution*” OR “Society 5.0”) AND (“Green Financ*” OR “Carbon Financ*” OR “Climate Financ*” OR “Environment Financ*” OR “Low Carbon Financ*” OR “Green Investment*” OR “Green Bond*” OR “Green Credit” OR “Green” OR “Green Manufacturing” OR "Green Innovation")

Total number of search results: (N=846)

↓

Arranging

Purification

Organizing Sieve: Year, document type, Subject area, source type, publication stage, and language (N=381)

Filtering year for incorporation: Upto end of April 2023

Screened the subject area for inclusion: All (Since I4.0 and I5.0 finds applications in every subject area)

Filtered search results for Inclusion: English (N=196)

↓

Assessing

Evaluation

Analysis Method: Content analysis, thematic analysis

- **Performance Analysis:** Publication trend, Most Influential article, etc
- **Science mapping:** Word clouds, major themes etc.

Agenda Proposal Method: Studying the literature and considering the open questions around each overarching topic

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Reporting

Style guide for reports: tables, graphs, and text

Limitations: Accuracy and completeness of bibliometric data from scopus

Support: No funding support received.

Figure 2. SPAR-4 SLR methodological framework as per (Paul et al., 2021)

3. Research Methodology

The present study follows the hybrid research approach of integrated reviews, which comprises systematic literature review (SLR) and bibliometric analysis. Both of the methods have significance for this study (Dhayal et al., 2023). SLR attempts to present a detailed investigation of the chosen research domain along with an explanation of the research questions (Agrawal et al., 2023). SLR follows a structured and systematic approach to identify conflicting results by highlighting the discrepancies of various studies. However, the bibliometric approach helps to analyse the various statistics of the huge scientific data and their related evolutionary nuances of the publication trend and citation analysis to identify the emerging research themes (Donthu et al., 2021).

This study aims to explore the emerging role of GF being deployed towards various activities and sectors of I4.0 and I5.0. This can be possible only through a critical review of the available research literature that spans various subject areas (Agrawal, et al., 2022; Agrawal et al., 2022). The present study utilizes an SLR to explore the available literature on GF, I4.0 and I5.0 and to identify how these revolutionary technologies are an asset to achieve sustainability. The adoption of a literature review helps to identify conceptual, theoretical, methodological and thematic development of the research domains (Hulland & Houston, 2020; Gopalakrishnan & Ganeshkumar, 2013). However, this review study is a combination of a domain-based review (Tranfield et al., 2003; Zhang et al., 2021; Deckers & Lago, 2022) and a framework-based systematic review (Paul & Benito, 2017; Sindhwani et al., 2022; Luthra et al., 2023; Yadav et al., 2023). To conduct a rigorous, detailed and comprehensive literature review, this study adopted the protocols of "scientific procedures and rationales for systematic literature reviews" (SPAR-4-SLR) (Paul et al., 2021). It comprises three stages, namely, assembling, arranging, and assessing, which have been mentioned in Figure 2. The SPAR-4-SLR protocol enables the dissemination of cutting-edge ideas and inspires agendas to develop knowledge in the review sector. This procedure assures meticulous planning, consistency in execution, and transparency, allowing for replication. Moreover, it offers a logical and pragmatic logic and provides transparency through reporting based on the many stages and substages (Reina et al., 2022). The SPAR-4-SLR methodology is superior to PRISMA methodology (preferred reporting items for systematic review and meta-analysis) protocols (Moher et al., 2015). Moreover, this protocol addresses the underlying limitations of previous review methods by providing more comprehensive guidance for conducting the study, such as the keyword search strategy, study selection, data extraction and analysis.

3.1 Assembling

This stage includes two substages. Identification is one of the substages that deals with finding articles that have an association between I4.0/I5.0 and GF. For this, the Scopus database was selected as the search engine because it has a large corpus of research articles (Singh et al., 2021). A combination of relevant keywords was used through a search string for the preliminary round of search results. Figure 2 shows the set of research questions, search strings, sources and time periods that acted as guides for coming to the result of 846 research articles.

3.2 Arranging

This result went through several rounds of purification, which finally yielded 196 research articles. Since I4.0/I5.0 are applied in almost every subject stream area, no inclusion and exclusion criteria were applied with respect to the subject domains (refer to Figure 2). Moreover, few more articles were removed after finding no relevance when their title, abstract and keywords were read. This stage helped reduce the corpus to a substantial number of 196 research articles.

3.3 Assessing

The final document corpus result of 196 articles was assessed through the 'Performance Analysis' of their publication trend. Additionally, 'Science Mapping' through word clouds and 'Cluster Analysis' of documents was performed to arrive at the various research thematic clusters that emerged among these articles. Here, the bibliometric method was used (Broadus, 1987; Derviş, 2020; van Eck & Waltman, 2010). The research propositions and the use of similar keywords of the thematic clusters helped in identifying the trend of this domain of GF and I4.0/I5.0. Additionally, future research directions and agendas were also concluded after reviewing the research gaps in the available literature.

4. Bibliometric analysis

In this section, we have performed a bibliometric analysis that helps to gather the statistical information of research articles in a particular domain (Raan, 2009). Previously, many scholars have applied descriptive statistics through bibliometric studies to analyse research trends and provide comprehensive insights into the research topic (Falagas et al., 2006; Liu et al., 2013; Agrawal, et al., 2023). Bibliometric-based quantitative statistics help to identify publication trends, influential authors, articles and highly contributing journals and countries (Detwal et al., 2023). The bibliometric analysis was conducted using R package software.

Bibliometric analysis is best suited to analyse such a large corpus of bibliographic datasets. The first research question (RQ1) is fulfilled by the performance analysis of the bibliometric data by analysing and summarizing the research productivity. For this, we have looked at the publication trend over the years along with their citations in this area. Additionally, we listed the top research articles to be looked at to get hold of this domain. Table 2 provides a summary of the most important data on the publishing pattern, including the number of publications, the countries involved, and the level of collaboration between the authors from 2012 to 2023 (April end).

Table 2. Main Information on publication trend.

Publication Information	**Results**
Timespan	2012 to 2023
Total number of publication	196
Rate of expansion per year %	18.55
Mean age of document	2.13
Average number of citations per published work	14.46
References	15151
Authors Information	
Authors	804
No. of authors with single-authored article	13
Multiple authorship per document	4.33
Global coauthorships %	41.84
Document Information	
Article	152
Review	44
Keywords plus	1364
Keywords of authors	830

Source: Compilation of authors using Bibliometrix R Package

Figure 3 shows the growth trend of publication articles in this research domain. The very first article that discussed I4.0 and the greener aspect of finance appeared in 2012, when Dawe (2012) discussed the role of 'Green Employment' in the 'Green Industrial Revolution'. Umezurike (2012) discusses the role of democratic setup for Nigeria's industrial development in combating climate change. It can also be seen that the publications did not pick up until 2017. However, the growth has been quite exponential from 2017 onwards. This increased research interest from the scholarly community is due to the United Nations embracing the SDG's agenda at the end of 2015. Subsequently, the Paris climate agreement came into effect at the end of 2016, which acted as a turning point for the transition towards the adoption of green and cleaner energy technologies. Some significant research work that came during that time is (Chen et al., 2016; García Ferrari, 2017), where the green development and role of green energy was being emphasized. Thus, it can be seen that from 2018 onwards, there has been a growing interest of academicians and scholars. As a result, publications in the domain of I4.0/I5.0 and GF have grown enormously.

Table 3 highlights the top journals on the topic of I4.0/I5.0 and GF. The top journals have been considered in terms of their total publications, while the top impactful journals take into account the total citations. Table 3 shows that in terms of top prolific journals, it is "Sustainability" followed by "Energies", "IEEE Access", "International Journal of Environmental Research and Public Health", and "Applied Sciences". The top impactful journals are "Journal of cleaner production", "Sustainability", "IEEE Access", "Energies" and "International Journal of Production Research".

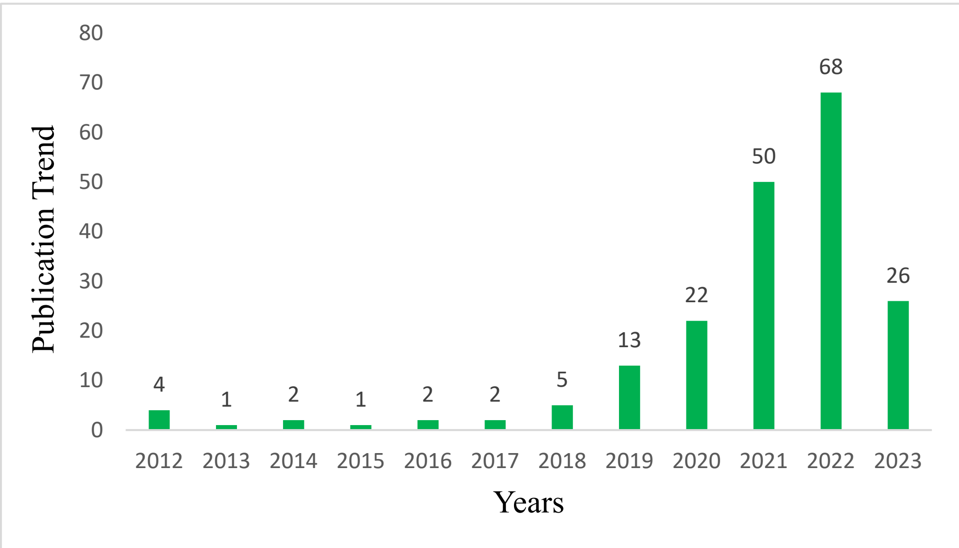

Figure 3. Publication Trend (Author's compilation)

Table 3. Top five journals

Prolific journals	OP	Impactful journals	OC
"Sustainability"	32	"Journal of Cleaner Production"	266
"Energies"	13	"Sustainability"	234
"IEEE Access"	8	"IEEE Access"	143
"International Journal of Environmental Research and Public Health"	4	"Energies"	91
"Applied Sciences"	3	"International Journal of Production Research"	82
Where OP= Overall publications, OC= Overall citations			

Table 4 shows the list of various top authors and top countries in terms of their publications and citations. Among the authors, Tsai W.H., Affandi H.M., Afrin M., Borysiak O., and Brych V. have published the most articles. On the other hand, Afrin M., Jin J., Tsai W.H., Gidlund M., and Guizani M. have received maximum citations based on their research work. Further observation reveals that emerging and developing nations such as China, Malaysia and India have contributed more than developed countries.

Table 4. Top notable authors and leading countries

Topmost authors				Top countries	
Authors	**OP**	**Authors**	**OC**	**Country**	**OP**
Tsai W.H.	3	Afrin M.	88	China	30
Affandi H.M.	2	Jin J.	88	United Kingdom	21
Afrin M.	2	Tsai W.H.	77	Malaysia	18
Borysiak O.	2	Gidlund M.	71	United States	14
Brych V.	2	Guizani M.	68	Spain	11
				India	10
				Italy	10
				Poland	9
				Portugal	8
				Australia	7

Where OP= Overall Publications, OC= Overall Citations

Table 5 shows the usage of the top keywords along with their times of occurrence. It can be seen that terms such as ‘sustainable development’, ‘Industry 4.0’, ‘industrial revolutions’, etc., have been repeated a maximum number of times. The overall keyword usage is also shown in Figure 4 in the form of a word cloud.

Table 5. Top Keywords

Top keywords	Frequency	Top keywords	Frequency
sustainable development	29	artificial intelligence	12
industry 4.0	28	embedded systems	12
industrial revolutions	21	green computing	12
green manufacturing	19	energy utilization	11
sustainability	19	industrial research	7
energy efficiency	16	green economy	7
Industry	13	climate change	7
Innovation	13	environmental technology	7

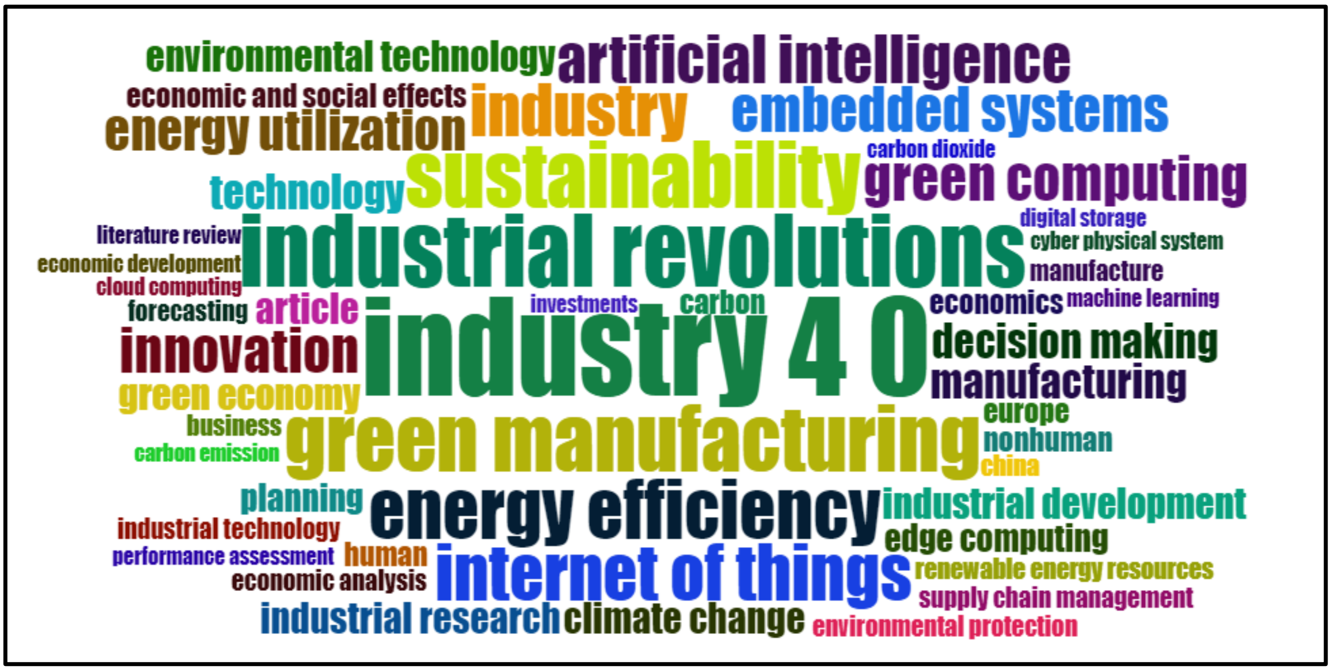

Figure 4. Keywords word cloud

Table 6 presents the list of the top 15 most cited publications in this research domain. The top research articles are Dev, Shankar, & Qaiser (2020), Le et al. (2021), and Huynh et al. (2020), with 193, 115 and 108 citations, respectively.

Table 6. Top most cited articles

S.no.	Source	TC	Contribution of the study
1.	Dev, Shankar, & Qaiser (2020)	193	Connects I4.0 with the CE ReSOLVE approach and proposes a roadmap for a sustainable supply chain.
2.	Le et al. (2021)	115	Discusses the prevailing challenges of I4.0 technologies in the context of financial market assets like green bonds and cryptocurrencies for portfolio diversification. The study finds that I4.0 assets and traditional equities are highly connected and pose a risk to investors.
3.	Huynh et al. (2020)	108	Investigates the role of portfolio diversification in green stocks, AI and robotics stocks in the context of I4.0. It suggests that such a portfolio has high volatility in short-term.
4.	Çalık (2021)	95	This agricultural case study applies a mix of AHP and TOPSIS approach in the I4.0 era context under the Pythagorean Fuzzy environment to select the green suppliers. It reveals that there are three most important criteria like quality, delivery and production.
5.	Bányai et al. (2019)	73	Describes I4.0 innovations like cloud and fog computing, RFID and big data analytics under the cyber physical system for the waste management models for municipal waste and other models like waste of electrical and electronic equipment (WEEE).

6.	Vrchota et al. (2020)	53	Sustainable green industry 4.0 (SGI 4.0) was proposed in the study to show how green processes in manufacturing through cleaner technologies can help in emission reductions and finally sustainability.
7.	Fraga-Lamas et al. (2021)	44	The study reviewed the concepts like Edge-AI and Green IoT (G-IoT) helps to reduce carbon footprint in the I5.0 context.
8.	Yin & Yu (2022)	34	The study focuses and highlights how the manufacturing firms can improve their performance in the areas of green knowledge creation and digital green innovation by working together with other enterprise firms.
9.	Bradu et al. (2022)	24	Sustainability is discussed, along with the importance of adopting green technology in I4.0.
10.	Ng et al. (2021)	10	It derives framework from the available literature and policies for the green financing to set up sustainable infrastructures under I4.0 to combat climate change.

5. Emerging research themes

Bibliometric analysis involves performance analysis where a particular research domain's performance is analysed through rigorous profiling of the selected corpus of articles to showcase the publication trend and find the top contributing journals, institutions, countries and authors along with the most influential articles. Apart from performance analysis, the bibliometric research method also makes use of science mapping through the temporal analysis of word clouds, which depicts the major topics that characterize that particular research theme, and network analysis through keyword co-occurrence, which reveals the major themes of that particular research topic’s intellectual structure. Therefore, with the help of network analysis, we consolidated various articles into six major themes or clusters accordingly. Cluster analysis is one of the most important parts of bibliometric research studies. It helps to find similar themes of articles based on the network of authors, their publications and co-citations.

To answer the second research question (RQ2), we used scientific mapping to couple citation data with the corpus's subject clusters. This research uncovered six separate clusters of themes in this area: green supply chain management (GSCM), green manufacturing practices (GMP), green innovations (GI), circular economy (CE), emerging economies, and net zero economy (NZE). It should be noted that most of these themes are highly interconnected and mutually assist each other in ensuring environmental sustainability. Therefore, the flow of GF initiatives in these themes will trickle down to the other themes as well and have ripple effects on the entire economy.

The summaries of these six themes or clusters are presented below.

5.1. Cluster 1: Green Manufacturing Practices (GMP)

GMP is the largest cluster, with keywords and topics such as "green technology", "green loans", "green IoT", "green energy", "green Industrial IoT", "smart factory", and "manufacturing processes". Several researchers have explained the importance of GMP, as it aims to reduce the impact of industrial operations on the environment. It becomes essential for the I5.0 transition, as it is built upon the previous industrial revolutions and imbibes the principles of sustainability and green practices.

Green manufacturing practices (GMPs) can support the sustainable use of resources, reduce environmental impacts, optimize waste, etc. In the I5.0 transition, the manufacturing process is highly energy efficient due to renewable energy usage. Therefore, GMP also supports circular business models through a closed loop supply chain. We need many GF investments in the GMP through incentives such as green loans, tax breaks and subsidies, suitable policy frameworks, etc. The developed and developing countries should push for GMP, as there are only finite resources that have to be used for sustainability so that the economies become resilient enough to mitigate the climate change issue.

In the current era, green technology is an improvement in promoting and implementing green development and mitigating negative externalities from the environment. It is a good indicator of increased output, longevity, and minimal interference with production. According to Alsamhi et al. (2021), unmanned aerial vehicles (UAVs) are a cutting-edge technology with great potential to boost economic productivity, cultural vitality in smart cities, and people's quality of life. UAV technology is also a supporting application for environmental preservation, surveillance, healthcare, agriculture, pollution monitoring, communication, transportation, public safety and disaster management. The authors have presented the green IoT via UAVs technology overview for a sustainable and smart world.

Fraga-Lamas et al. (2021) investigated the factors that affect the creation of edge artificial intelligence (Edge-AI) and Green IoT (G-IoT) systems. Despite the enormous promise of IoT-enabled digitalization of industries for the shift towards sustainability, they have not yet made a significant impact. To address these problems, the green IoT (G-IoT) paradigm has arisen as a study field. The study concludes that CO_2 emissions depend on Edge-AI G-IoT devices and the level of green energy generated by countries.

Tabaa et al. (2020) have proposed a smart grid framework of I4.0 technologies with an integration of renewable energy sources for optimization and efficiency mission of (IoT) to promote the "Green Industrial IoT (GIIoT)". The enabling technologies of GIIOT are AI, green energy, and mobility, and the applications of GIIOT are smart factories, smart agriculture, smart grids, smart cities, smart transportation and smart health.

Mohamed et al. (2019) investigated the benefits and opportunities of smart techniques in the manufacturing sector within the I4.0 domain to reduce energy consumption in smart industries. The study suggested including a cloud manufacturing services layer, cyber-physical system (CPS), blockchain-based middleware and fog manufacturing services layer to support such opportunities. The study concluded that I4.0 technologies can provide a significant reduction in energy consumption and a reduction in cost in smart factories. Shahatha Al-Mashhadani et al. (2021) revealed that the IoT, digital gadgets, and smart factories that are totally reliant on digital technologies are influencing manufacturing processes. Digital manufacturing can only thrive if all relevant parties have access to the tools necessary to participate in the ecosystem. According to the study's findings, digital technologies are enhancing manufacturing effectiveness and efficiency for sustainable ecosystems.

5.2. Cluster 2: Green Innovation (GI)

The second largest cluster pertaining to this research domain is Green innovations. The popular keywords include "renewable energy adoption", "energy efficient", "environmental sustainability", "green growth", "environmentally friendly innovations", "green technology", and "collaborative innovations". Under this current theme, various researchers have focused on the role of GI, as it is most likely to remain critical and significant for future industrial transitions because of its potential to foster competition to ensure resource efficiency and resilience.

The I5.0 transition includes many advanced technologies, such as blockchain, AI, big data analytics, and IoT. that are environmentally friendly. Currently, greener innovations have been happening continuously in these technologies to ensure that renewable energy adoption is increased, smart grids are deployed, manufacturing becomes energy efficient, etc. Greener innovations in these technologies will ensure that I4.0 to I5.0 will be based upon the three pillars of I5.0, namely, sustainability, human machine centricity, and resilience.

In modern times, green innovation is a key indicator for maintaining environmental management. It has become a vital tool for organizations to attain sustainable competitive advantages and stay alive in the long run, as it contributes to creating new products and reducing environmental risks. Gavurova, et al. (2022) investigated the dynamic relationship between monetary risk, renewable energy technology expenditures, and carbon impact in OECD nations using the "environment Kuznets curve" (EKC) paradigm. The research shows that reducing carbon emissions, increasing the use of renewable energy, and boosting environmental sustainability are all possible thanks to better management of financial risk. The ecological footprint is significantly negatively impacted by economic globalization, and energy use increases the footprint.

Ghosh et al. (2020) developed a market expansion-based model considering competition and cost-sharing contracts. Due to the dominating retailer and the presence of rival manufacturers, the retailer and manufacturer share more greening costs than the corresponding decentralized channel. Mubarak et al. (2021) suggests that I4.0 has a positive impact on open innovation and leads to green innovation behaviour in firms. In regard to encouraging environmentally friendly innovation and green behaviour among businesses, policymakers should take part in open innovation. For that, organizations should be encouraged to adopt and use I4.0 technology and collaborative innovation interactions because they promote an environment for long-term, environmentally friendly developments.

Song et al. (2022) have looked at the development of environmentally friendly technologies as an instance of I4.0. Monetary, social, ecological, and technical issues all play a part in the growth of the manufacturing sector, and the authors have analysed the connection between environmental legislation, green technology advancement, and total factor productivity to do so. The findings show that green technology development is "forces" by environmental legislation via external pressure and that green technology advancement significantly boosts total factor productivity in businesses through increases in unit labour productivity.

Wang et al. (2021), for the first time in the literature, looked at how technological innovation can help foster green growth. It investigates the relationship between technical innovation and green growth in the context of human capital, economic growth, globalization and R&D spending. According to the findings, technological advancement, GDP, human capital, economic globalization, and R&D expenditures are all necessary for green growth in the long run.

5.3. Cluster 3: Circular Economy (CE)

The next research cluster pertains to the CE, where researchers highlight its significance and contribution towards sustainable development. The CE approach protects and restores the planet's natural ecosystems and its limited supplies of materials while still meeting the indefinite demands of a rising population and providing for future generations (Adimuthu et al., 2022). Integration of advanced technologies with the principles of CE can ensure sustainable business practices through waste reduction and resource efficiency (Agrawal et al., 2022). Here, the major keywords are "sustainable production", "resource efficiency", "waste reduction", "blockchain", "green transportation", "green buildings", "sustainable manufacturing", "green logistics", and "green practices".

GF initiatives will ensure that the financial needs to support the infrastructure and technologies needed for the CE business are met. This includes investment flows for green buildings, green logistics, green transportation, green supply chain, etc., to ensure that the entire economy is built upon the CE model. However, this is only possible when green financing is made available for circular product designs, recycling and remanufacturing facilities, etc.

In recent times, CE has substituted the end-of-life notion by developing alternative and renewable sources of energy to reduce harmful effects on the environment (Agrawal et al., 2022). It transforms the consumption and production process by creating value from waste materials. It looks beyond the current consumption-based pattern and aims to develop a closed loop system for sustainability.

Samadhiya et al. (2023a) offers critical insights into the sustainability approach through natural resource-based view theory (NRBV) by examining the relationship between CE, blockchain technology and total productive maintenance. Patra et al. (2023) integrates SCM and CE practices into supply chain finance to identify emerging research themes and delineate their future directions.

Bag et al. (2021) developed a theoretical model that links the resources of I4.0 and its effects on sustainable production and CE capabilities. The study identifies that the key resources of I4.0 that can promote CE and sustainable manufacturing are green design, green logistics, production systems, information technology, human resources, management leadership, project management, big data analytics and collaborative relationships. The adoption of I4.0 technologies is positively correlated with both sustainable production and CE capabilities.

Pinheiro et al. (2022) proposed a new approach to impart the effects of CE on industry performance by circular product design (CPD). The results indicate that the technologies of I4.0 have a favourable impact on CPD, AI and big data analytics. Finally, there is a favourable correlation between the adoption of a CE and market success, and the impact of stakeholders can stimulate the adoption of circular strategies by suppliers who are responsible for supplying smart products.

Rehman Khan et al. (2022) examined how blockchain could be used to boost efficiency in the CE of the China-Pakistan Economic Corridor (CPEC). Supply chain management that takes into account the CE has environmental and financial benefits for businesses. In addition, the financial and ecological outcomes of a company are positively correlated with green practices.

5.4. Cluster 4: Green Supply Chain Management (GSCM)

The fourth largest research cluster is related to GSCM. It encapsulates keywords such as "green technology adoption", "green transportation", "closed loop supply chain", "waste management", and "reverse logistics". Here, the researchers have demonstrated how the GSCM plays a crucial role in the I5.0 transition. It addresses the reduction of waste involved in raw material sourcing, production, distribution and finally the disposal of the product after its end of life. GSCM has developed as a widely acknowledged environmental approach that enhances ecological performance throughout the whole supply chain, not just at individual companies (Govindan et al., 2016). GSCM will encourage the use of GMP and adoption of circular business models and help to achieve NZE through increased use of green technological innovations. Industries everywhere are scrambling to embrace green supply chain practices in response to rising external challenges and consumer expectations (Muduli et al., 2020). Therefore, GSCM is capable of assisting the I5.0 transition.

In the past two decades, the concept of the green supply chain has been widely discussed because of its increasing need for pollution reduction and conservation of resources. It requires downstream and upstream efforts to satisfy the emerging environmentally conscious expectations in the supply chain. The application of a green supply chain is cost and service effective and thus promotes a high level of sustainability. Detwal et al. (2023) lists the research trend of the ongoing developments in supply chain management, taking into consideration the effect of I4.0 techniques. (Frederico et al., 2023) mentions that the resilience of disruptive SCM processes and their integration with I4.0 technologies in the wake of COVID-19 had a positive impact. Balon (2020) reviewed the performance of green supply chain management (GSCM) in industries in three categories: GSCM pressures (corporate social responsibility, rules and regulations imposed by government and green market), GSCM practices (internal environment management, green products, eco-design, waste management, and product recovery and quality product) and GSCM performance (financial, environmental and operational).

Giovanni & Cariola (2021) looked at how lean methods and environmentally friendly supply chains were impacted by the innovation strategy industries implemented using I4.0 technology. The research examined whether process innovation may be used to strengthen ties between efficiency, sustainability, and green supply chain management. The findings of the study show that leanness helps suppliers collaborate on environmental programmes and has a favourable impact on both operational and environmental performance. The blockchain's potential to encourage environmentally friendly practices throughout manufacturing firms' supply chains was studied by Mubarik et al. (2021). The results of the study confirm the positive effect of blockchain on green supply chain practices. This study advises policymakers and managers to implement I4.0 technologies such as blockchain because of its numerous advantages, particularly for manufacturing companies. First, it increases integration across the supply chain, enhances the planning of demand and supply to reduce extra production, enables industries to adopt just-in-time production and saves costs. The study highlights the importance of technological orientation to emphasize the significance of technology for environmentally friendly and green supply chain practices. Dev et al., (2020) attempts to simulate reverse logistics and investigate how the market dynamics of product diffusion impact the financial and environmental performance of an inventory and production planning (I&PP) system. The simulation model captures the main aspect of I4.0, which is the virtualization of factory activities. The findings point to the appropriate adoption patterns for the trade-off between environmental and economic performance. When adopting socially influenced green products, special attention should be given to operational factors and their associated costs. Factors such as the size of the end-user market and collection investment determine how often a product is returned to the reverse logistics system.

5.5. Cluster 5: Emerging Economies

The next cluster is Emerging economies, which has popular keywords such as "alternative energy sources", "green solutions", "fintech", "blockchain", "AI", "governance models", and "local communities". Emerging economies face the severe brunt of climate change. Sustainable business operations are hard to implement due to the scarcity of capital, as their financial resources are quite limited. However, the government can play a supportive role here by creating a business environment conducive enough for domestic and foreign investors to invest. Regulations can be relaxed for green projects to ensure their rapid implementation. The barriers can be identified and targeted selectively through policy support to enable the GF to make the economies sustainable and resilient.

Although I4.0 increases the productivity and competitiveness of industrial operations, its prime focus is never on sustainability. The study by Satyro et al. (2022) examines the potential implications of implementing I4.0 in developing countries. A developing country case study of SMEs was conducted by Yüksel (2020). Due to the lack of a technical skillset, I4.0 applications were not adopted. Moreover, only those industries that produced highly technical products were the ones where I4.0 applications were found to be used. Therefore, even after being aware of the advantages, the firms were hesitant to shift to these advanced technologies, as they were unsure about the possible trade-offs between the advantages and the risks involved. Mukherjee et al. (2023) have compared both developing and developed countries to identify the set of possible barriers to I4.0 adoption. It concluded that internal capability-related barriers should be targeted by developing countries and that technology-related barriers should be the focus of developed countries. Sindhwani et al. (2022) conducted an extensive study on the enablers of I5.0 and proposed a framework for resilience.

5.6. Cluster 6: Net Zero Economy (NZE)

The final research cluster is NZE, with significant keywords such as "carbon neutrality", "net zero emission", "decarbonization", "net carbon economy", "net zero", "energy management", "emission control", "life cycle analysis" and "sustainability". The I5.0 transition through the support of GF will help to achieve NZE. It acts as a channel by making provisions for the required investment to meet the significant needs of many projects, processes and practices of business models that are moving towards a net carbon economy (Agrawal et al., 2021).

Worldwide, severe pressure has been placed on industrial operations to reduce their environmental impacts. Now they are looking towards cleaner production modes by using digital technologies to ensure that net-zero economy practices are being adopted. Agrawal et al. (2023) identified the drivers responsible for adopting advanced technologies so that CE business models can move towards net zero. The study suggests that organizations should come together to ensure that sustainability practices are being adopted through advanced technologies. Agrawal et al. (2023) identifies emerging I4.0 technologies in the form of drivers for sustaining NZE practices for SCM. Similarly, (Agrawal et al., 2023) offered practical insights into the sustainability challenges of SCM in the context of CE by listing several barriers, drivers and their respective challenges. Moreover, (Yadav et al., 2023) emphasize the significance of NZE in achieving sustainable development by adopting various digital technologies through a theory-driven approach.

Mishra et al. (2022) further unravelled the NZE domain in the supply chain context. Most of the major work in this field mostly revolves around carbon emission control, energy management, decarbonization, and life cycle analysis. It was found that for net zero economies, a connecting role exists between digital technology adoption, optimized resources and CE. Emodi et al. (2022) shows that the role of GF in boosting Greenfield investment is crucial for a decarbonization/net-zero economy. It was identified that over time, the environmental barriers had declined significantly as countries have been making efforts through climate action plans to increase their clean energy usage. As a result of various public policies, the barriers to clean energy adoption have declined, but the need for mobilizing private capital has arisen.

This puts pressure on GF investments to become channelized for greenfield projects oriented towards renewable energy. Demartini et al. (2023) discuss the role of electric vehicles in a net-zero economy model through the principles of circular business operations and stakeholder theory. The results on various stakeholders show that the electric vehicle transition will lead to automation and thereby more job losses. Although the role of GF in such a transition turns out to be beneficial in terms of environmental implications, a compromise is being made on the economic aspects.

6. Discussion

GF investments will not only help in the I5.0 transition but also play a crucial role in achieving most of the SDGs. The pillars of I5.0 and the SDGs aim to benefit both the planet and the people by not compromising profits. The goal of a low carbon economy is also attainable then. Affordable and clean energy (SDG7) is possible due to advanced energy-efficient technologies focusing on reducing energy use. Industry, Innovation and Infrastructure (SDG 9) is achievable through GSCM, GMP, and CE business models. Sustainable cities and communities (SDG11) are one of the outcomes of the I5.0 transition, where S5.0 will be the end goal. Decent work (SDG8) through a smart workforce that will be focused upon human–machine centricity. Clean water (SDG6) and responsible consumption and production (SDG12) can be achieved if GF investments in the I5.0 transition are focused upon CE practices. Similarly, several other SDGs, such as climate action (SDG13), partnerships (SDG17), etc., are one of the end results of the I5.0 transition. Therefore, it can be said that GF can not only facilitate the I5.0 transition but also support sustainable development for all stakeholders involved.

6.1 Challenges associated with the I5.0 transition

The GF offers significant opportunities for a sustainable future for the I5.0 transition. However, it will not be easy for companies to make this transition, as they will require huge upfront investment, which may deter them from adopting these sustainable solutions, and their profit margins may be affected. Additionally, various regulatory barriers and the existence of nonuniformity in the policies make it difficult for business firms to align their growth for sustainability. Moreover, sustainability reporting lacks standardization across different industries and sectors, which makes it difficult for investors to deploy sustainable finance products and solutions. Investors have a short-term myopic focus on the profitability of their company's growth instead of long-term sustainability goals. Last, the sustainability performance of GF investment-related data is either not available or not reliable enough to gauge their performance and impact on the environment and society. A list of such challenges has been categorized in Table 7.

6.2 Discussion on the research findings

In the present study, I4.0, I5.0, and S5.0 were integrated into GF through a bibliometric, SLR and thematic analysis of 196 research articles extracted from the Scopus database. The authors have applied various applications of bibliometric and thematic analyses to identify the author, institute, sources, and country statistics along with keyword co-occurrence analysis. In this section, we answer the formulated research questions. The present study also proposes a framework (refer to Figure 5) to show the interconnecting role between I4.0, I5.0, S5.0 and sustainable development.

Table 7. Major challenges in the I5.0 transition through GF

Categories	Sources
Financial support	
• Implementation of green technologies involve high upfront costs and continuous investment flow which deters their adoption by businesses. • Limited availability of different forms of GF instruments and options. • Hesitation on the grounds of uncertainty about the financial returns. • Investors perceive it as a highly risky investment opportunity among all the available options. • Lack of data availability about their significant impacts and benefits.	(Dhayal et al., 2023; Hemanand et al., 2022; C. Li et al., 2023; Mehdiabadi et al., 2022; Ng et al., 2021; Skobelev & Borovik, 2017)
Government policy support	
• Regulatory bottlenecks as the policies are not uniform across sectors and countries. • Policies are not business-friendly. • No one-stop policy measures exist currently in many developing countries. • Non-standardized regulations about GF exist. • Very limited incentives from the government for their adoption. • Limited collaboration and coordination exist between different government agencies.	(Adel, 2022; N. Ahmad et al., 2023; C. Li et al., 2023; Maddikunta et al., 2022; Nahavandi, 2019; Paschek et al., 2022; X. Xu et al., 2021)
Technology related	
• Non-availability of technical expertise for implementing such advanced green technologies. • Difficult to maintain interoperability of the I5.0 transition system and green technologies integration. • Scaling up at a large scale by maintaining that sustainability fabric is unaffected.	(Aslam et al., 2020; Hu et al., 2022; Jafari et al., 2022; Massaro, 2021; Skobelev &

• Reliable and durable service maintenance will remain an issue due to the limited trained personnel. • The digital infrastructure to support large data analytics is needed. • Various technological risks need to be assessed. • Businesses are exposed to risk of cyber security threats.	Borovik, 2017; Tlili et al., 2023; Yavari & Pilevari, 2020; Yin & Yu, 2022)
Sustainability challenges of S5.0	
• Ensuring CE models in green supply chains will be tough task. • Large-scale life cycle assessment of green technologies needs to be carried out for assessing their significance. • Reliance on sustainable raw materials and other resources through green manufacturing is challenging across industries. • Risk of severe job loss and rise of social tensions.	(Huang et al., 2022; Pereira* et al., 2020; Turner et al., 2022; Carayannis et al., 2021; Carayannis et al., 2022)
Miscellaneous	
• Many firms especially SME's are unaware of the benefits and role of GF for the I5.0 transition. • Resistance from within the old polluting industries and other stakeholders whose interests are compromised in the I5.0 transition. • Cultural and societal barriers exist. • Public support is missing.	(Adel, 2022; N. Ahmad et al., 2023; Alexa et al., 2022; Doyle et al., 2020; Huang et al., 2022; Kurniawan et al., 2019; Leng et al., 2022; Maddikunta et al., 2022; Nahavandi, 2019; Paschek et al., 2022; X. Xu et al., 2021)

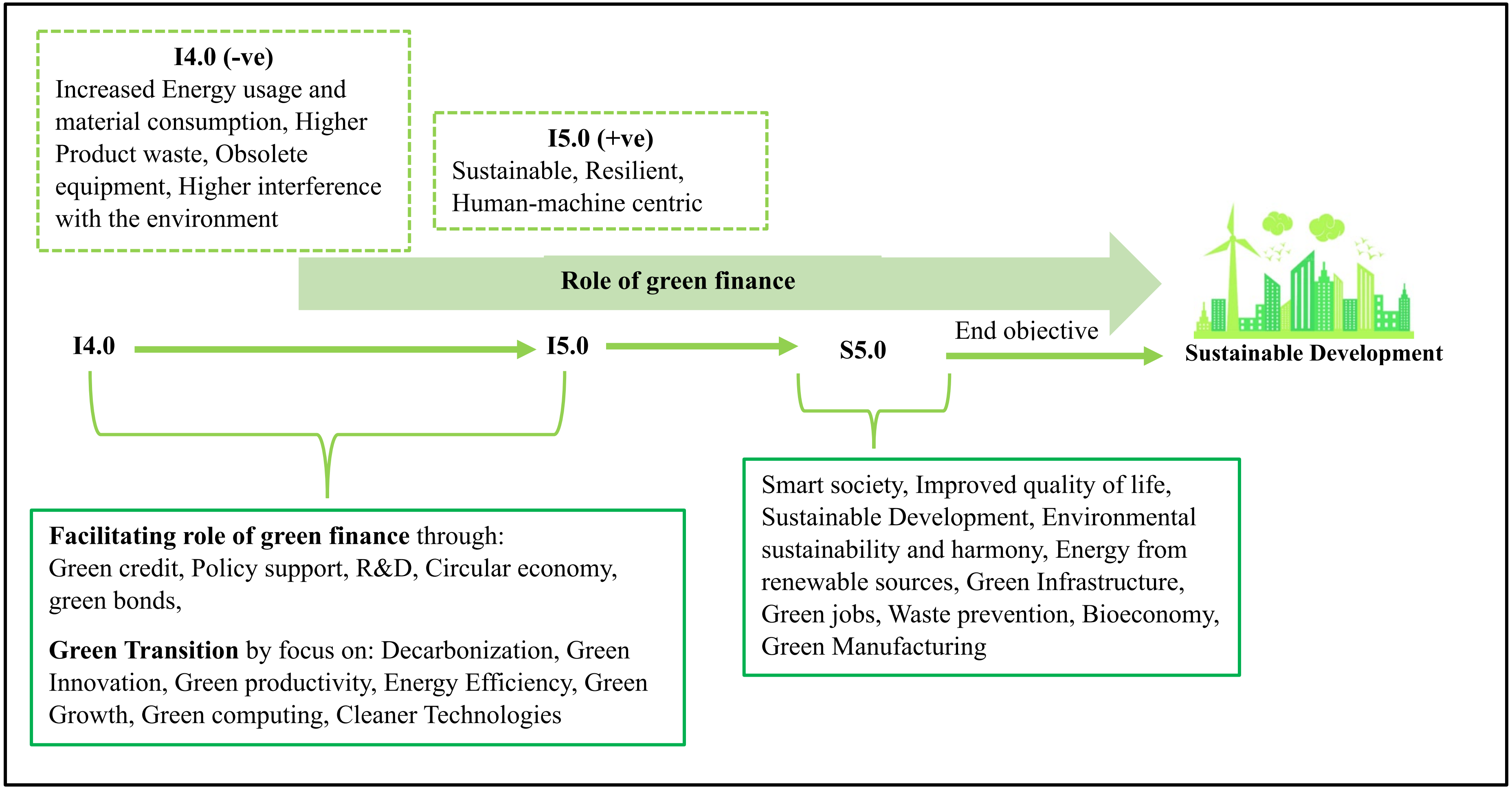

Figure 5. Interconnected role between I4.0, I5.0, S5.0 and GF

RQ1. What has been the publication trend, along with their top publication journals, most cited authors, top countries in terms of publications, major keywords, and top cited articles in this research domain?

To answer the first research question, the first article on GF and I4.0 appeared in 2012 by Dawe (2012). Later, the number of articles in the given area started increasing from 2018-2022. The majority of the articles in this period were focused on green development, green energy and cleaner energy technologies. In recent years, green innovation along with industrial technologies has gained the interest of scholars. The top publication journals in this research area are "Sustainability" and "Energies", with 32 and 13 publications, respectively, whereas "Journal of Cleaner Production" has the highest citation of 266. The top most cited author is Afrin M. and Jin J., with 88 citations, who researched the behaviour of GF and the transition of GF and cleaner technologies. The research reveals that China has the highest number of publications, followed by the United Kingdom and Malaysia. "Sustainable development" and "Industry 4.0" are the major keywords used in the literature, whereas environmental technology is an emerging keyword.

RQ2: What has been the thematic development of the major research clusters in this area?

To analyse the second research question, the present study adopted scientific mapping through thematic analysis of subject clusters. The six separate clusters are GMP, GI, CE, GSCM, Emerging Economies, and NZE. In GMP, the focus revolved around green technology, Edge-AI, Green IoT, GIIoT and CPS to enhance the GMP (Alsamhi et al., 2021; Fraga-Lamas et al., 2021; Tabaa et al., 2020; Mohamed et al., 2019; Shahatha Al-Mashhadani et al., 2021). Green innovation includes the I5.0 transition, which includes advanced technologies such as blockchain, AI, big data analytics, and IoT. that are environmentally friendly (Ahmad, 2022; Ghosh et al., 2020; Mubarik et al., 2021; Song et al., 2022). CE comprises GF initiatives and technologies to ensure CE flow in industries through CPD, AI and data analytics (Bag et al., 2021; Pinheiro et al., 2022; Khan et al., 2022). GSCM plays an integral role in the I5.0 transition to reduce waste material and carbon emissions and maximize energy usage by encouraging GMP and circular models, blockchain and I&PP (Balon, 2020; De Giovanni & Cariola, 2021; Mubarik et al., 2021; Dev et al., 2020). Emerging economies revolve around green and sustainable projects by enabling GF to make economies sustainable and resilient (Satyro et al., 2022; Yüksel, 2020; Mukherjee et al., 2023; Sindhwani et al., 2022). Finally, NZE needs the I5.0 transition through GF for green projects that lead towards a net carbon economy through CE, life cycle analysis, clean energy and electric vehicles (Mishra et al., 2022; Emodi et al., 2022; Demartini et al., 2023).

RQ3: What are the potential future research directions in this domain?

Proposition 1

UAVs with IoT technologies, a human-centric approach, the development of Edge-AI G-IoT systems, the impact of GIIOT on I5.0, optimization algorithms for energy efficiency, the application of technological innovations and cost benefit analysis in green practises are the major themes that have prominent future research potential. Researchers should explore the integration of S5.0 with these research areas so that it can further benefit I5.0 technologies.

Proposition 2

Public policies for greener innovation, ecological footprint, open innovation and green innovative performance, human health and life cycle assessment are the major research themes that create synergistic benefits to multiple greener innovation practices. Implementing such practices requires the support of government, policymakers and investors.

Proposition 3

Cleaner technology, innovations, sustainable production, sustainability implications of I5.0, and indicators for the circularity of I5.0 are the major themes to explore in the future. It requires a conceptual framework to enhance the use of emerging technologies on industrial performance to promote circularity and thus to list challenges for CE practice adoption.

Proposition 4

Green supply chains, blockchain technology, I4.0 solutions for green supply chains and I5.0 technologies for GSCM are still at a nascent stage. Therefore, more emphasis should be placed on developing a framework for GSCM to achieve SDGs.

Proposition 5

In this theme, most research articles revolve around the adoption of alternative energy sources to reduce carbon emissions and dependence on fossil fuels to promote green financial solutions and enable I5.0 transition. It is therefore an important aspect to pursue future directions using

I5.0 technologies to improve job opportunity, inequality, and other social dimensions. This might be a very powerful future research agenda.

Proposition 6

The majority of the research articles have noted the importance of carbon neutrality, net-zero emissions and green financial solutions and integrated the I5.0 transition for industries and entrepreneurs. To identify the role of fintech in GF solution for the NZE could be interesting to explore in future research.

6.3 Potential future research directions

Table 8 below answers RQ3 by presenting the list of potential research questions of the six major emerging themes that can be explored by scholars.

Table 8. Major themes of the corpus documents

Cluster 1. Green Manufacturing Practices (GMP)	
Proposed Future Research Questions (RQs)	**Sources**
RQ1. How unmanned aerial vehicles (UAV) equipped with IoT devices can help reduce pollution and energy consumption further. RQ2. To identify how IoT can further be deployed for S5.0. RQ3. In what ways can Green IoT be a solution to the Human-centric approach of sustainability? RQ4. Identifying the domains and sectors where implementing such technologies can create a much larger impact. RQ5. To propose a roadmap for the successful development of Edge-AI G-IoT systems in the nations. RQ6. To study the impact of GIIOT on I5.0 and the upcoming Industrial Revolution I5.0. RQ7. Creating optimisation algorithms to address a wide range of energy efficiency problems and potential savings in this area. RQ8. Listing and clearly defining the role of government and regulators in promoting green manufacturing practices. RQ9. Exploring the application of technological innovations for optimizing the green manufacturing process in industrial operations. RQ10. Quantifying the benefits and costs associated with adopting green practices in I5.0. RQ11. Finding ways through which green manufacturing can help in resource efficiency and waste reduction.	(Alvarez et al., 2021; Dhayal et al., 2023; Hemanand et al., 2022; Jafari et al., 2022; Majerník et al., 2022; Ng et al., 2021; X. Xu et al., 2021; Yin & Yu, 2022)
Cluster 2. Green Innovations (GI)	
Proposed Future Research Questions (RQs)	**Sources**

RQ1. How can public policies be targeted for faster adoption of greener innovations? RQ2. Understanding the nexus of financial risk and ecological footprint in developing countries. RQ3. To investigate the sector-wise comparison of open innovation and green innovative performance. RQ4. Analyse how green growth is affected by policies that encourage innovation, globalisation, R&D, and investment in people. RQ5. Do greener innovations also affect human health in a positive manner apart from environmental sustainability? RQ6. How to distinguish greener innovations from the other forms of innovations. RQ7. What factors can influence organizations and firms to adopt greener innovations faster? RQ8. Understanding the holistic approach of sustainability initiatives and the associated trade-offs involved in implementing them. RQ9. Applying the life cycle assessment on green innovation products for ensuring sustainability and circularity. RQ10. Listing the enablers and barriers responsible for the adoption and diffusion of GI in I5.0.	(Al Faruqi, 2019; Dhayal et al., 2023; Hemanand et al., 2022; Hu et al., 2022; B. Li & Song, 2022; Ng et al., 2021; Sindhwani et al., 2022; Yin & Yu, 2022; Zizic et al., 2022; Brahmi et al., 2023)
Cluster 3. Circular Economy (CE)	
Proposed Future Research Questions (RQs)	**Sources**
RQ1. How can the waste be further reduced through cleaner technology and innovations? RQ2. How can I5.0 further be integrated with the business operations for moving towards the CE? RQ3. How can the physical internet help the logistics industry for promoting circularity? RQ4. To investigate the adoption of sustainable production in SME's to motivate CE capabilities.	(Atif, 2023; Austin & Rahman, 2022; Bag et al., 2020; Dev, Shankar, & Qaiser, 2020; Durán-Romero et al., 2020; Farooque et al., 2019;

RQ5. To propose a framework for the enhanced use of emerging technologies on industrial performance to promote circularity. RQ6. To analyse the potential challenges of the CE for adopting GF products in the industries. RQ7. How to address the technological and organizational challenges of I5.0 for the CE. RQ8. Understanding the sustainability implications of I5.0 for 6Rs (Reuse, Recycle, Reduce, Rethink, Refuse, Repair). RQ9. Designing the standard metrics and other uniform indicators for the circularity of I5.0. RQ10. Listing the risks and challenges for the CE practices adoption.	Nascimento et al., 2019; Rehman Khan et al., 2022; Samadhiya et al., 2023b)
Cluster 4. Green Supply Chain Management (GSCM)	
Proposed Future Research Questions (RQs)	**Sources**
RQ1. Identify the major drivers and barriers hindering the I5.0 supply chain. RQ2. Deploying green supply chain for SMEs and emerging economies. RQ3. To learn how blockchain technology may change environmentally responsible business practises within the service sector. RQ4. Assessing the influence of I4.0 solutions on green supply chains in major sectors. RQ5. In what ways can the I5.0 technologies be leveraged for GSCM? RQ6. How to integrate the GSCM into the I5.0 systems and design to ensure that profitability and competitiveness remain unaffected. RQ7. How can the CE's closed-loop supply chain be put into action and incorporated into existing systems? RQ8. Designing a framework for GSCM to achieve SDG's. RQ9. What GSCM policies can reduce the carbon footprint through green technology adoption?	(Cañas et al., 2020; Chalmeta & Santos-deLeón, 2020; Daú et al., 2019; Dossou, 2018; Esmaeilian et al., 2020; Fazal et al., 2022; Frederico, 2021; Karmaker et al., 2023; Kasinathan et al., 2022; Maddikunta et al., 2022; Manavalan & Jayakrishna, 2019; Mastos et al., 2020; Minculete et al., 2021;

RQ10. Understanding the impact of GSCM on logistics and green transportation.	Voulgaridis et al., 2022; G. Yadav et al., 2020)
Cluster 5. Emerging Economies	
Proposed Future Research Questions (RQs)	**Sources**
RQ1. How can Humans and robots compete and complement each other in a labour-abundant economy? RQ2. What policy measures can be taken by developing countries for greener I5.0? RQ3. Which alternative energy sources can reduce the dependence on fossil fuels for sustainable I5.0? RQ4. How can we help developing nations speed up their I5.0 transition by promoting and supporting green financial solutions? RQ5. Identify the relevant barriers and drivers for emerging economies for the I5.0 transition. RQ6. Explore the role of partnerships and collaborations to enhance GF solutions and product adoption. RQ7. Understanding the impact on job loss, inequality, and other social dimensions due to I5.0. RQ8. What role can technologies like fintech, blockchain, AI etc. play in enabling the I5.0 transition? RQ9. Application of GF for Governance models. RQ10. Role of local communities and their participation in enhancing the GF solution.	(Basl, 2017; Chauhan et al., 2021; Li, 2018; Longo et al., 2020; Luthra et al., 2020; Luthra & Mangla, 2018; Mukherjee et al., 2023; Özdemir & Hekim, 2018; Raj et al., 2020; Tamvada et al., 2022; X. Xu et al., 2021)
Cluster 6. Net Zero Economy (NZE)	
Proposed Future Research Questions (RQs)	**Sources**
RQ1. Identifying the industries needing immediate attention for making shift to carbon neutrality. RQ2. How policymakers can prepare the Decarbonization pathways for the Net-zero emissions. RQ3. In what ways can electric vehicle adoption speed up decarbonization and CE? RQ4. Listing down the key barriers and suggesting steps to overcome them for NZE.	(Bag et al., 2020; Dwivedi et al., 2022; Kumar et al., 2021; Nascimento et al., 2019; Pham

RQ5. What incentives can be given for GF solutions adoption in I5.0 for enabling the net zero emissions? RQ6. What green technologies can assist in achieving NZE economy? RQ7. Understanding the consumer Behavioral factors responsible for the scaling up GF solutions. RQ8. What steps can be taken to address the financing gap for NZE and I5.0 transition for the small entrepreneurs. RQ9. How can the circular supply chain be integrated with the NZE through GF solutions? RQ10. What role can fintech play as a GF solution provider for a NZE?	& Ahn, 2018; G. Yadav et al., 2020; Agrawal, et al., 2023)

7. Implications of the research

7.1 Theoretical implications of research

The present study has provided a detailed overview of the integration of GF, I5.0 and S5.0 to achieve sustainability; thus, it contributes to the existing knowledge on all three emerging dimensions, i.e., GF, I5.0 and S5.0. The study is a pioneering examination of the research introduction and the application of GF, I5.0 and S5.0 for sustainable development. In the comprehensive analysis of the research findings, we have identified five theoretical implications that provide a future route for sustainable practices. First, the study's findings assist future researchers in understanding the breadth and limitations of this study. Second, the findings are helpful for academicians and policymakers by inclining their attention to the emerging and relatively obscured research domains that are vital for the adoption of I5.0 technologies along with GF. Third, academicians have become familiar with the most prominent authors, sources, countries and institutions in this domain. Fourth, the cluster analysis findings provide scholars with critical information regarding important works that can be regarded as the foundation of this study area. Fifth, the proposed future research proposition explores the emerging research themes for further research. In the future, policymakers and researchers can look to this study as a significant reference source.

7.2 Practical implications of research

The present research study provides important implications for researchers, policymakers, investors and governments. Public and private industries and investors should accept the need for I5.0 technologies and green projects to promote sustainability. It is evident that I4.0 has made human life simpler through digitalization, IoT things, and automation. The transition to I5.0 will further ensure that industrial development is human-resilient, sustainable, and resilient through personalized touch to products and services. To ensure that this ongoing transition leads to less carbon emissions and environmental degradation, the role of GF is considered important. There exists an interconnected role between I4.0, I5.0, S5.0 and GF (refer to figure 5). It is the mediating role of GF that can help in the smooth transition from I4.0 to I5.0 so that the objective of S5.0 can be fulfilled. I5.0 forms the symbiotic relationship between three aspects for S5.0. They are social aspects (human machine centricity), ecological aspects (zero emissions), and technological aspects (green innovations). The drawbacks of I4.0 are further complemented by I5.0, which focuses on environmental sustainability.

7.3 Policy implications of research

The present article provides various policy implications that can be adopted by the relevant authorities to mitigate I5.0 technologies, GF and S5.0 for sustainable development and thus minimize financial loss. In this study, it can be seen that policymakers could provide critical roles by supporting the green and circular projects that enable I5.0 technologies by optimizing the green manufacturing process in industrial operations and reducing financial risk. Moreover, policy makers should mandate greener innovative performance, greener innovations, sustainability initiatives, cleaner technologies and energy-related regulations to motivate industries to adopt CE.

8. Conclusion and Limitations

This study explores the growing area of GF and its adoption towards I4.0 and I5.0. These two domains have been interlinked through integrated review methodology. It is determined that the I5.0 transition through the help of GF can aid in combating climate change, carbon emissions, and environmental degradation. Science mapping and performance analysis were used in this integrated review study to answer the overarching research questions. Based on the review of the thematic clusters, we made future research question propositions. Additionally, the study has suggested many challenges that need to be overcome (Table 7) for the successful I5.0 transition along with future research directions that can be taken up by future researchers (Table 8). The present article has some limitations that can be addressed in future research. First, the authors considered only the Scopus database for the extraction of the article. Hence, in the future, multiple databases can be used for data extraction. Second, the authors have used the limited keywords in the study that can be modified as per the on-going research trends. Third, the present study is limited to only journal articles, so in the future, researchers can consider other articles with multiple diversifications of the relevant studies. Fourth, future studies can investigate the barriers and enablers in the SLR article based on the adoption of GF and I5.0 technologies in the CE. Fifth, the search query was limited to articles published in English only; thus, omitted research articles should be explored in the future.

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Consent to Participate As Corresponding Author, I confirm that the manuscript has been read and approved for submission by all the authors.

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