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Roles of innovation in achieving the Sustainable Development Goals: A bibliometric analysis

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ABSTRACT

As we approach the midpoint of the Agenda 2030 programme, scientists are increasingly reliant on innovative solutions to help bring us closer to achieving the Sustainable Development Goals (SDGs). This study aims to analyse the intellectual structure of academic literature on the SDGs, Innovation, and Science, Technology and Innovation (STI).

Using a database of 544 English-language publications from Scopus and Web of Science published between 2015 and 2023, we employ a three-pronged approach comprising bibliometric analyses, SDG mapping and text-mining techniques. Our findings indicate that innovations in one cluster defined in the analysis display economic, social and environmental dimensions. Furthermore, the underlying roles of innovation in the literature are found to relate to promoting sustainable development, driving economic growth, enhancing enterprise performance and strengthening policies. Within the sample literature, all 17 goals were identified by the SDG Mapper. Among the 5Ps (People, Planet, Prosperity, Peace and Partnerships), there was a clear preponderance of articles on Prosperity. The text mining of titles and abstracts indicates that the term "sti" is less commonly associated with the SGDs than "innovation". However, there is some evidence that the term "innovation" is used in titles and abstracts to attract a broader audience. Our study highlights research gaps and identifies opportunities for future studies.

Introduction

Innovation has emerged as a critical driver of sustainable development, with the United Nations Sustainable Development Goals (SDGs) providing a comprehensive framework to address the various dimensions (People, Planet, Prosperity, Partnership and Peace) of global challenges. As we are already at the midpoint of the Agenda 2030 programme, with the global community striving to accelerate progress towards achieving the SDGs, an understanding of the role of innovation has become of paramount importance. Progress towards some SDGs lags seriously behind, especially in low-income countries, where the effects of the COVID-19 pandemic and subsequent crises have been particularly severe. Despite these challenges, the SDGs are still achievable, and none of their targets are unattainable (Sachs et al., 2023).

Given the universal and interconnected nature of the SDGs, any innovations directed towards their attainment must meet multiple requirements. Our study aims to explore this crucial aspect of the relationship between innovation and the SDGs. Schot and Steinmueller (2018) have argued that the complex nature of SDGs requires transformational solutions that go beyond innovation alone; therefore, it would seem that a combination of Science, Technology and Innovation (STI) is warranted.

STI is becoming increasingly relevant in attempts to achieve the SDGs (Walsh et al., 2020), primarily due to the rapid pace of technological progress (Managi et al., 2021) and disruptive technologies such as artificial intelligence (AI) (Di Vaio et al., 2020). Innovations can substantially impact the costs associated with making progress, offering opportunities to develop new solutions, approaches and environmental actions that can contribute to sustainable development (Marini Govigli et al., 2022). Thus, innovation and partnership play a crucial role in tackling the complex and interconnected challenges of sustainable development (Oliveira-Duarte et al., 2021).

Overall, two streams of literature are highly relevant to our research: studies exploring the role of innovation in achieving the

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SDGs, and existing literature reviews and bibliometric analyses of the relationship between innovation and the SDGs.

Studies within the first stream of literature have focused on the various aspects of environmental sustainability. Khan et al. (2022) observe that green innovation moderates the correlation between a company's financial performance and its progress towards environmental and social SDGs. Meanwhile, Ullah et al. (2021) emphasise the need for government support for small and medium-sized enterprises in adopting green innovation. Wei et al. (2023) and Zhou et al. (2020) explore the promotion of green innovation in sustainable supply chains, while Wang et al. (2022) highlight the role of green knowledge management in strengthening organisations.

Circular Economy (CE) practices have also been discussed in relation to the SDGs. Schroeder et al. (2019) highlight the direct contributions of CE practices to SDGs 6–8, 12 and 15, while Dantas et al. (2021) suggest that combining CE with Industry 4.0 technologies could enhance these contributions.

The literature also examines the role of environmental policies (Wang et al., 2022), energy innovation (Baloch et al., 2022) and technological innovation (Anwar et al., 2022) in reducing emissions and promoting carbon mitigation. STI can lead to lower levels of pollution, increased productivity and competitiveness, and the sustainable use of natural resources (Martínez & Poveda, 2021).

At the organisational level, studies have considered the role of publicly funded incubators for STI-based startups (Surana et al., 2020), community-led initiatives (Henfrey et al., 2023), and multi-stakeholder partnerships formed through collaborative innovations (Mariani et al., 2022) to create an enabling environment for sustainable development. Calabrese et al. (2021) emphasise the mediating role of service and frugal innovations in firms' contributions to the SDGs. Drilling down to the community level, Imaz and Eizagirre (2020) discuss how firms in a social solidarity economy can contribute to the sustainable development agenda through responsible innovation. Meanwhile, Alarcon Ferrari et al. (2021) and Nogueira et al. (2022) highlight the role of innovations such as citizen science, social strategies and intentionally sustainable communities in addressing the SDGs, particularly in rural settings.

The second stream of literature includes reviews and bibliometric analyses that explore the relationship between the SDGs and the business sector (Azmat et al., 2023; Pizzi et al., 2020), AI technology (Di Vaio et al., 2020), technological innovations (Thavorn et al., 2021), innovative aspects of the water–energy–food nexus (Correa-Porcel et al., 2021), eco-innovation (Fatma & Haleem, 2023; Peregrina et al., 2023), social innovation (Eichler & Schwarz, 2019; Meyer, 2022), health and well-being (Sweileh, 2020), education (Prieto-Jiménez et al., 2021), responsible innovation (Di Vaio et al., 2022) and frugal innovation (Albert, 2022).

Building on these prior works, our study differs, however, from existing research in two ways. First, the studies cited above focus primarily on the contributions made by specific innovations to achieving the SDGs. However, it is also important to understand which innovations dominate the existing literature. Hence, we adopt a holistic approach that considers innovation more broadly, and gain a more comprehensive perspective by studying innovation and STI in relation to the SDGs. To achieve this, we address the following research questions (RQs):

- RQ1: What is the intellectual structure of the field of study?
- RQ2: Which SDGs can be found in the literature on innovation, STI and SDGs?
- RQ3: How is the role of innovation in relation to the SDGs presented in the existing literature?

The second way in which our study is distinct from existing research can be seen in our methodological approach, which combines the use of three separate techniques to address the RQs. More specifically, we use co-occurrence analysis to identify critical themes and generate a visualisation of the intellectual structure using VOSviewer, in response to RQ1. For RQ2, we use the SDG Mapper tool to identify relevant SDG goals and targets within the titles, abstracts and keywords. Finally, we address RQ3 by defining the role of innovation in the quest to achieve the SDGs using a text-mining technique.

Our study contributes to the literature in several ways. First, we provide an overview of current knowledge and new insights into the intellectual structure of the relationship between innovation, STI and SDGs. Second, our research tracks and emphasises the links between innovation and specific SDGs. Third, while certain prior bibliometric studies relate to the SDGs (Meschede, 2020; Prieto-Jiménez et al., 2021; Sweileh, 2020), none have used mapping or text-mining techniques; our study demonstrates the usefulness of these techniques in addressing this topic. Finally, by adopting the 5Ps (People, Planet, Prosperity, Peace and Partnerships) framework, the present study aims to offer an understanding of the SDGs beyond the traditional three-pillar approach.

Scope and boundary of the review

Innovation and STI

The concept of innovation has been defined in various ways, encompassing environmental (Ullah et al., 2021), social (Marini Govigli et al., 2022), technological and institutional innovations (Anwar et al., 2022; Liu et al., 2022). While using a broad definition of innovation can pose challenges in measuring and monitoring, it allows a comprehensive understanding of the concept, which is particularly valuable for interdisciplinary studies.

Several types of innovation have recently emerged as promising drivers for achieving the SDGs, including collaborative innovations (Mariani et al., 2022), eco-friendly innovations (Miao et al., 2023), co-innovation (Adomako & Nguyen, 2022; Fielke et al., 2018) and responsible innovation (Imaz & Eizagirre, 2020; Ranabahu, 2020). The COVID-19 pandemic has increased innovation in, for example, the biopharmaceutical sector, contributing to sustainability (Piñeiro-Chousa et al., 2022). The concept of "innovability" has been proposed by De la Vega and De Paula (2020) as a strategic approach for companies seeking to achieve both competitiveness and sustainability.

To achieve sustainability, significant changes are needed in the public's thinking, behaviour, production and consumption. Scientific expertise alone is not sufficient to develop and implement effective solutions: intellectual capital is also needed, including access to information, knowledge and experience (Faraji et al., 2022). Open innovation principles (Chaurasia et al., 2020), social innovation and disruptive technologies (Ciampi et al., 2020) have all helped to accelerate the sharing of knowledge.

STI distinguishes itself from innovation in its inclusion of the terms "science" and "technology", thus positioning itself as the driving force behind progress: science can advance knowledge by improving our understanding through observation, experimentation, and research and development (R&D), leading to the creation of techniques and technologies that offer public benefit. Technology is the practical application of scientific knowledge to create products and services. While innovation can result merely from thinking "outside of the box", technological progress can only be achieved through scientific discovery and research which invent and develop technology (ESCAP, 2015). Technology links science with innovation.

The technology gap is one of the primary causes of persistent inequality between nations (Naudé & Nagler, 2015), and the key difference between developed and developing countries lies in knowledge levels. Eliminating the knowledge gap, as suggested by Ozkaya et al. (2021), can close both development and income gaps. To address this issue, the Addis Ababa Action Agenda acknowledges the role of STI in achieving the SDGs and provides funding to support

Table 1
Distribution of innovation-related SDG goals and targets by 5Ps.

	Knowledge	Science	Technology	Innovation	ICT
People 	SDG 2.3		SDG 1.4		SDG 4.4
		SDG 2.a agricultural research, technology			SDG 4.b
		SDG 3.b medical research	SDG 6.a recycling, reuse technology		SDG 5.b
Prosperity 			SDG 7.1 SDG 7.b	SDG 9	SDG 8.10
		SDG 7.a clean energy research technology		SDG 8.2	SDG 9.c
			SDG 9.2 SDG 9.4 SDG 9.a	SDG 8.3	
		SDG 9.5/9.b scientific research, technology, innovation			
Planet 		SDG 12.a scientific and technological capacity			
		SDG 14.3	SDG 12.5		
		SDG 14.4			
		SDG 14.a scientific knowledge, research, technology			
Partnership 			SDG 17.7		
	SDG 17.6 STI and enhance knowledge-sharing through a global technology facilitation mechanism				
	SDG 17.8 technology bank and science, technology and innovation capacity-building mechanism, ICT				
	SDG 17.16 share knowledge, expertise, technology				
Peace 	SDG 16.10				

Source: Prepared by the authors based on screening of the Global Indicator Framework

progress to this end (United Nations, 2015). Furthermore, the Technology Facilitation Mechanism (TFM) and the engagement of United Nations entities and other stakeholders facilitate the exchange of information, best practice, experience and policy advice (United Nations, 2020).

The 5Ps of Sustainable Development Goals

Regarding the frameworks used to understand the SDGs, previous studies have traditionally focused on three principal pillars: social inclusion, economic growth and environmental protection. However, recent global challenges – such as the COVID-19 pandemic, military conflicts and energy and climate shocks – have led to a broader understanding of sustainable development. The 2030 Agenda introduced two additional components, Partnership and Peace, (Dumpe & Guevara, 2020), thus expanding the framework to include five essential dimensions: People (SDGs 1–5), Prosperity (SDGs 7–11), Planet (SDG 6, SDGs 12–15), Peace (SDG 16), and Partnership (SDG 17), known as the 5Ps of the Sustainable Development Goals (Ki-moon, 2019).

To facilitate the monitoring of progress towards the SDGs, an innovative approach was adopted which resulted in a set of indicators for global governance. The Inter-Agency and Expert Group, in collaboration with the Statistical Commission, developed the Global Indicator Framework (GIF) for the SDGs. The GIF comprises 231 unique indicators, some repeated across multiple SDG targets (United Nations, 2022). This approach offers flexibility and adaptability as methodologies and data sources evolve and expand between 2015 and 2030, providing a robust basis for monitoring progress towards the SDGs.

Innovation-related keywords in the SDGs

The SDGs do not explicitly define the role that innovation may play in achieving them. However, the specific types of innovation that may drive the achievement of each SDG are not stated too. To better understand the relationship between innovation, STI and the SDGs, we conducted a detailed analysis of the 17 SDG goals and the 169 targets that underpin them, as outlined in the GIF. To this end, we identified the terms linked to innovation and STI in the GIF, first creating a list of all the terms we encountered and labelling them as innovation-related keywords. We were then able to group these keywords into five broad categories: knowledge, science, technology, innovation and information and communication technology (ICT). Finally, we distributed the targets that included the keywords into these categories, which we then aligned with the 5Ps, as shown in Table 1, which is formed of five columns representing the five categories (Knowledge, Science, Technology, Innovation and ICT) and five rows representing the 5Ps (People, Prosperity, Planet, Partnership and Peace). We thus identified the targets or terms that we expected to find in the sample database. From this basis, it was then possible to compare the expected and actual occurrences of innovation-related keywords in the literature by examining the terms, and the frequency with which they appeared, using the SDG mapping tool.

We identified 31 (out of 169) targets that mentioned at least one innovation-related term. The term "innovation" was itself mentioned in SDG 9 and targets 8.2, 8.3, 9.5 and 9.b. The term "STI" was observed in SDGs 17.6 and 17.8, and the terms "research" and "science" were repeatedly mentioned, with 14 and 9 occurrences respectively. However, the most frequently used term was "technology" (including ICT), which appeared 33 times. Technology was found to be relevant across four dimensions (People, Prosperity, Planet and Partnership). However, it is important to note that technology alone cannot achieve sustainable development, due to the possibility of rebound effects (Giovannini & Roure, 2017). The United Nations recognises the crucial role played by technology but, at the same time, highlights the need for it to be integrated with science and innovation to achieve the SDGs (Sachs et al., 2022).

Methods and materials

Bibliometric analyses are commonly employed in sustainability-related reviews due to their comprehensive and systematic approach (Azmat et al., 2023; Cortés et al., 2021; Meyer, 2022). In our methodology, we combined the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021) with the flow plan proposed by Zupic and Čater (2015). Our flow plan comprised five main stages: (1) research design, (2) compilation of bibliometric data (integrating the PRISMA 2020 flow diagram), (3) analysis, (4) visualisation and (5) interpretation.

To cover the relevant literature comprehensively, we conducted a search using the ISI Web of Science (WOS) and Scopus databases

(Aravindaraj & Chinna, 2022; Fatma & Haleem, 2023; Idrees et al., 2023).

Inclusion and exclusion criteria

To ensure the reproducibility of our results, we established precise inclusion and exclusion criteria and performed a comprehensive search of keywords, titles and abstracts across both databases. Our preliminary review revealed that authors frequently mention the SDGs and innovation in their abstracts to appeal to a wider audience. To narrow our search, we focused particularly on article titles, as our preliminary review showed that authors generally include the term "innovation*" in their title if innovation is a core aspect of their study. We first used the search query: title, abstract, keywords = ("sdg*" OR "sustainable development goal*") AND title = "innovation*". This query identified 1374 records (Scopus n = 826; WOS n = 548) (Fig. 1). We then conducted a second query: title, abstract, keywords = "sdg*" OR "sustainable development goal*" AND "science, technology, and innovation", which yielded 91 records (Scopus n = 60; WOS n = 31). Overall, our initial search generated 1465 results.

We applied the following filters: (a) Document type: Articles, (b) Language: English, (c) Publication years: 2015–2023, and cleaned the data to remove duplicate entries and address any missed keywords, titles or abstracts. Following these procedures, 571 relevant records remained.

We applied further exclusion criteria – (a) SLRs and (b) bibliometric analyses – to narrow the selection during the screening process. Following a content analysis of titles and abstracts, 15 SLRs and 12 bibliometric analyses were excluded, resulting in a total of 544 studies remaining for further analysis (Fig. 1). From this sample, it can be seen that the number of publications has grown exponentially over the period in question, from only two in 2015 to 185 as of 11 November 2023.

Bibliometric analysis and visualisations

The analysis in this study was performed using VOSviewer software version 1.6.19, a tool designed to create and visualise co-occurrence networks. We utilised two types of visualisation: network visualisation and cluster density visualisation; both used only the keywords for each article in our sample – those chosen by the authors and those generated automatically by the Keyword Tool.

In the network visualisation, keywords are depicted as labels accompanied by circles, where the size of the circle corresponds to the weight of the keyword. The weight of a keyword reflects its importance and is calculated through various metrics, including link weight, total link strength weight and occurrence weight. The score attribute indicates any numerical properties of a keyword (e.g. average publication year score or average citation score). The VOSviewer technique groups closely linked keywords into individual clusters

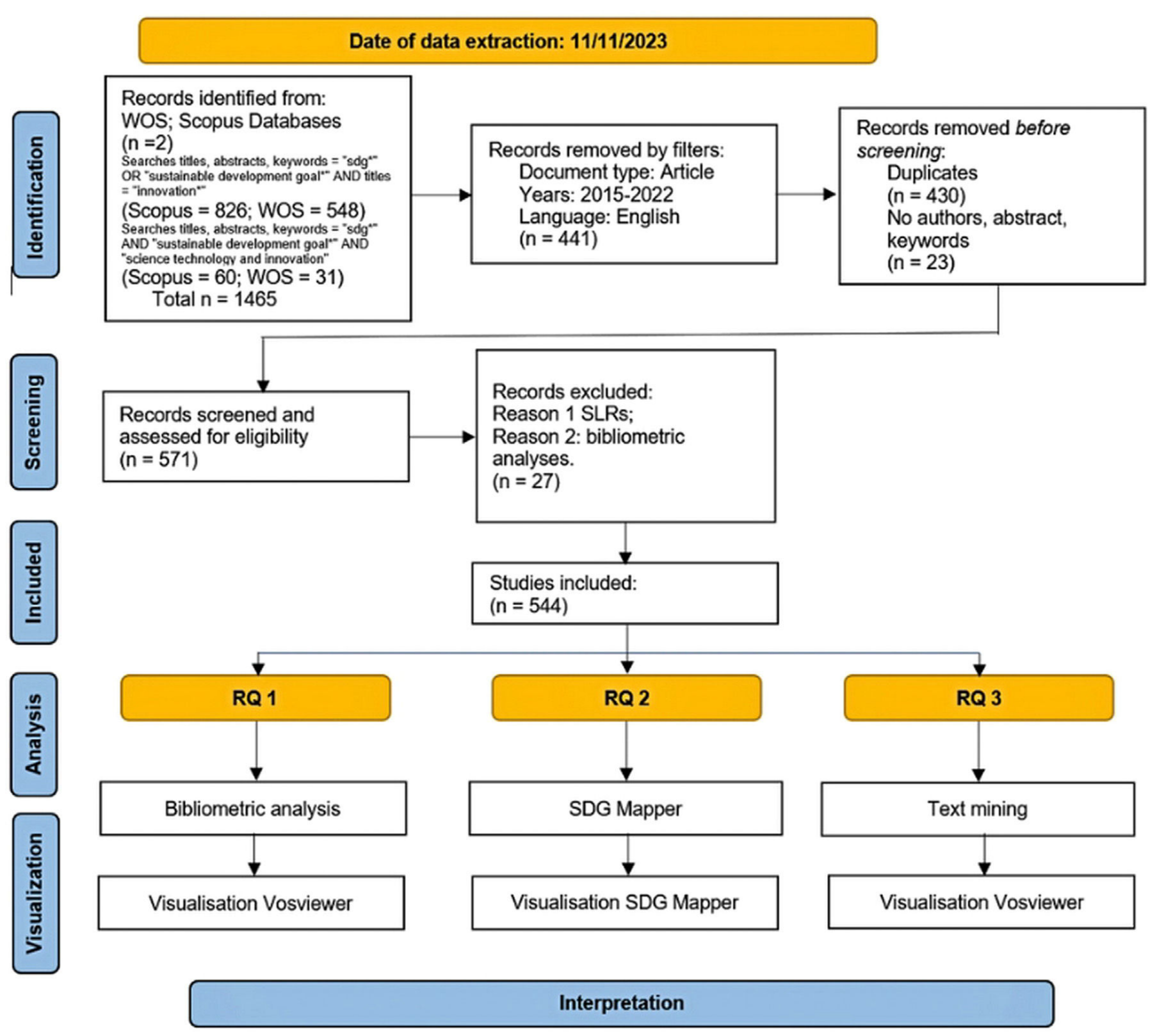

Fig. 1. PRISMA flow diagram and methods.Sources: Figure created by the authors

which are colour-coded. The colour of a circle is thus determined by the cluster to which it belongs, and links between circles are represented as lines (van Eck & Waltman, 2023).

Cluster density visualisation, in contrast, focuses on the occurrence and popularity of keywords. Similarly to network visualisation, keywords are represented as points, and the saturation of the point's colour is determined by the number of keywords in its neighbourhood and the weight of the neighbouring keywords.

Both visualisations offer a comprehensive and visually appealing representation of networks and clusters, enabling a deeper understanding of the relationships between the terms within the sample database and their relative densities (van Eck & Waltman, 2023).

SDG mapping

To answer RQ2, we utilised a web platform called "Knowledge Base for the Sustainable Development Goals", which includes the SDG Mapper tool. This platform serves as a knowledge hub for EU policies, indicators, and data related to the SDGs. The SDG Mapper uses natural language processing (NLP) techniques to detect the SDGs mentioned in the uploaded bibliometric records (European Commission, 2021). Once references to the SDGs have been identified, machine learning algorithms are then applied to analyse the data in the sample database and establish connections between the bibliometric records and the relevant SDGs. This process utilises rule-based techniques to identify specific keywords or phrases associated with each SDG.

The results of the analysis are presented in various visualisations. The bar charts provide an overview of the SDGs identified and their relative importance in the text, offering insights into the frequency and prominence of each SDG. The bubble charts show the relevance of the SDG goals and targets within the records, illustrating the distribution and interconnectedness of the SDGs. These visualisations enable an understanding of the representation and importance of different SDGs within the analysed bibliometric records, and facilitate a comprehensive mapping and analysis of SDG-related knowledge.

Text-mining techniques

The text-mining feature of the VOSviewer facilitated the generation of a term map that relies on NLP algorithms (van Eck & Waltman, 2011). In contrast to the network and cluster density visualisations, the text-mining technique examines the titles and abstracts of the sample database. In the VOSviewer, a noun phrase is defined as a sequence of one or more consecutive words in which the last word is a noun and any preceding words are nouns or adjectives. The two-dimensional map shows the placement of terms according to their relatedness, with closer proximity indicating a stronger relationship. This tool determines the relatedness of terms based on their co-occurrence within the records.

Results

What is the intellectual structure of the studied field?

The cluster density visualisation

The co-occurrence analysis identified 2915 keywords within the sample database. We focused on keywords that occurred at least five times, in line with the default threshold set in the VOSviewer. A thesaurus file (n = 356 keywords) was prepared to merge synonyms and plurals and identified 220 keywords that met the threshold criteria. Fig. 2 provides insights into the density and interconnectedness of the keywords within the sample database, highlighting the relationships and patterns between them.

In density visualisation, we focus on colour saturation and the distance between keywords. Here, the clusters are located tightly around the main keywords due to the precision with which we selected our sample database. The keywords "sdgs", "sustainability" and "sustainable development" are found in the red cluster, while "innovation", "technology" and "green innovation" are in the blue cluster. The keyword "innovation" is closely related to "sdgs", "sustainability" and "sustainable development", as evidenced by the 76, 46 and 45 links respectively between these words. Furthermore, we noticed that keywords such as "sdgs", "sustainability", "sustainable development", "innovation", "impact", "co2 emissions" and "technological innovation" exhibit high colour saturation, indicating their prominence in terms of the amount of research dedicated to them within the sample database. The keyword "sti" is found in the purple cluster, which includes keywords such as "science" and "innovation policy".

As we might expect, the term "sdgs" had the highest occurrence weight – 212 – among the keywords, indicating that it appeared in 212 articles within the sample database. The weight of the link attribute – signifying the number of links the keyword "sdgs" had with other keywords – was 211, indicating that it appeared together with different keywords in 211 articles. The weight of the total link strength attribute for "sdgs", representing the cumulative strength of all the links this term has with other keywords, was 1153.

Since the first search query was based on the term "innovation*", we identified words containing this term. Among the 220 keywords mentioned more than five times, 18 that included "innovation*" were identified, with a total of 469 occurrences. The red cluster displays a higher frequency (n = 10) of innovation keywords. Table 2 summarises the information gathered on innovation keywords, their occurrences and their weight within the clusters.

The keyword "innovation" belongs to the blue cluster, with an occurrence weight of 138, a link weight of 187 and a total link strength of 806. The most significant keywords by total link strength weight included "technological innovation", "green innovation" and "eco-innovation". The two most recent keywords are "financial innovation" (average publication year score of 2022.8) and "green innovation" (2022.3). The three most cited keywords are "innovation policy" (average citation score of 41.91), "frugal innovation" (34.38) and "technological innovation" (33.83). Thus, 86 % of the articles were related to these 18 keywords, which can be considered the main themes of our study.

The network visualisation

The network visualisation created in the VOSviewer provided further insights into the clustering of keywords within the sample database. The VOSviewer formed five clusters in the network visualisation (Fig. 3). The sizes of the clusters varied considerably, with a substantial difference between the largest, red cluster (n = 72) and the smallest, purple cluster (n = 25).

The red cluster emphasises three topics driven by "sdgs". Firstly, social aspects are shaping the "future" through "social innovation" and "social entrepreneurship", corporate social responsibility ("csr"), "responsible innovation" and "responsible research and innovation". The second topic encompasses the adoption of "eco-innovation", "open innovation" and "circular economy" principles. Finally, the third topic involves economic aspects such as "performance", "management", "systems", "industry" and "industry 4.0", "firm", "business model innovation", "frugal innovation" and "product innovation", and the "adoption" of "smart" and "digital" tools to create new "perspectives".

The green cluster represents two crucial areas in which innovation plays a significant role. The first encompasses "technological innovation", driving "economic-growth". The second highlights the relationship between "renewable energy", "co2 emissions", and "consumption" patterns and the interconnections between these factors, known as the "nexus".

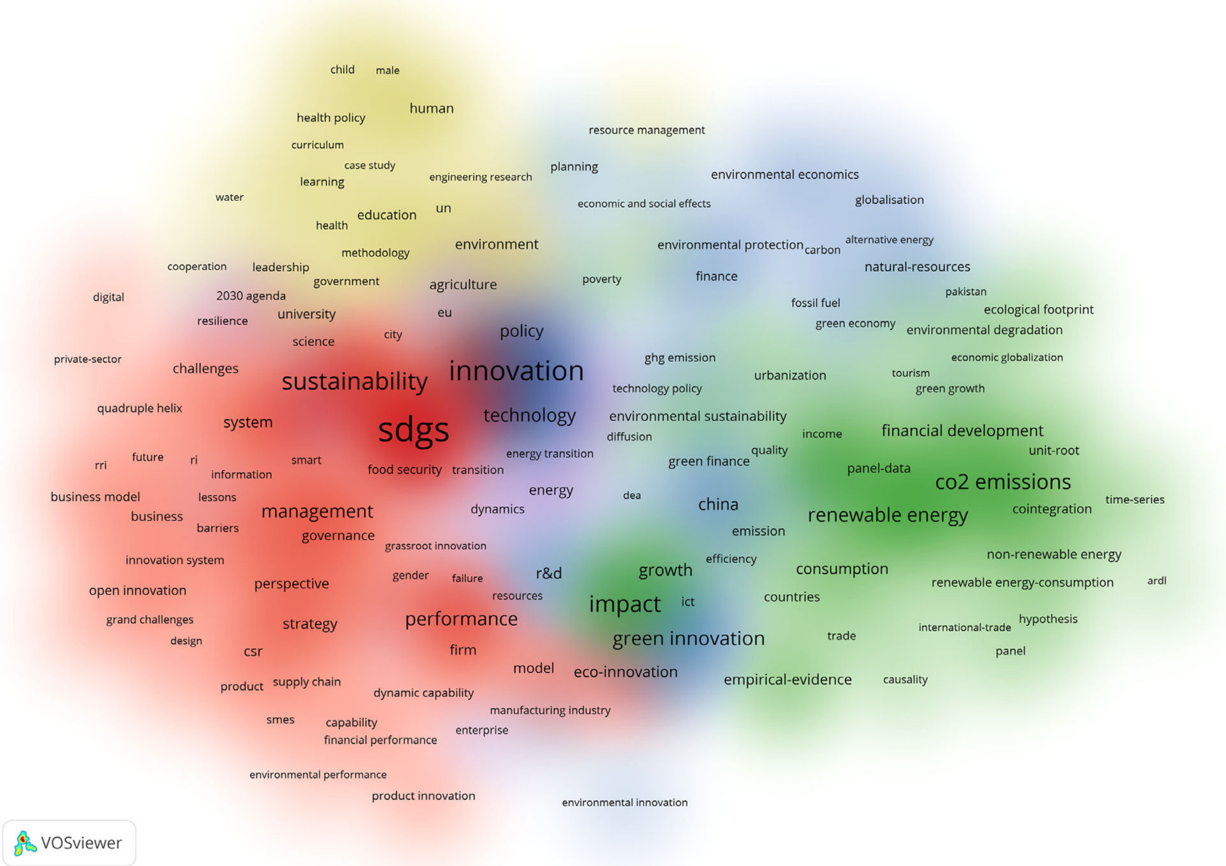

Fig. 2. The cluster density visualisation of the sample database on innovations, STI and the SDGs.Sources: Figure created by the authors using VOSviewer 1.6.19

The blue cluster includes a general discussion of “innovation” and “technology”, alongside related terms such as “r&d” and “ict” as necessary prerequisites for development. Another theme in this cluster is concerned with green aspects, such as the green economy, green finance, green growth, green innovation and green technology, all of which aim to promote greater environmental awareness.

The keywords in the yellow cluster centre on two main topics: education and health. The education aspect emphasises the incorporation of sustainable development “principles” into “higher education” “curricula” through innovative “methodologies” and “leadership” approaches. The health topic examines “health policy”, “challenges” and potential improvements, particularly in “Africa”.

The purple cluster focuses on promoting “transitions” using “sti” to tackle “climate change” and “food security” and achieve a more “resilient” future through “policy”.

Table 2
List of innovation-related keywords in the co-occurrence analysis.

#	label	cluster	weight <Links>	weight <Total link strength>	Weight <Occurrences>	score <Avg. pub. year>	score <Avg. citations>
1	innovation	Blue	187	806	138	2021.5	15.34
2	technological innovation	Green	146	641	69	2022.3	33.83
3	green innovation	Blue	129	427	59	2022.3	20.17
4	social innovation	Red	87	175	39	2021.3	9.13
5	eco-innovation	Red	100	215	30	2021.5	22.27
6	innovation policy	Purple	64	130	22	2021.2	41.91
7	open innovation	Red	50	86	15	2021.3	12.87
8	sti	Purple	30	43	14	2021.5	9.00
9	frugal innovation	Red	42	69	13	2019.5	34.38
10	sustainable innovation	Red	47	62	12	2021.3	17.25
11	innovation system	Red	50	88	10	2021.7	9.00
12	product innovation	Red	41	80	10	2021.1	28.9
13	ri (responsible innovation)	Red	37	54	9	2021	11.78
14	rri (responsible research and innovation)	Red	30	44	7	2019.7	22.57
15	business model innovation	Red	25	43	7	2021.4	12.14
16	environmental innovation	Blue	22	28	5	2021.2	15.8
17	financial innovation	Green	39	46	5	2022.8	21.8
18	grassroot innovation	Purple	22	23	5	2021.8	10.8

Source: Data were identified through the VOSviewer 1.6.19.

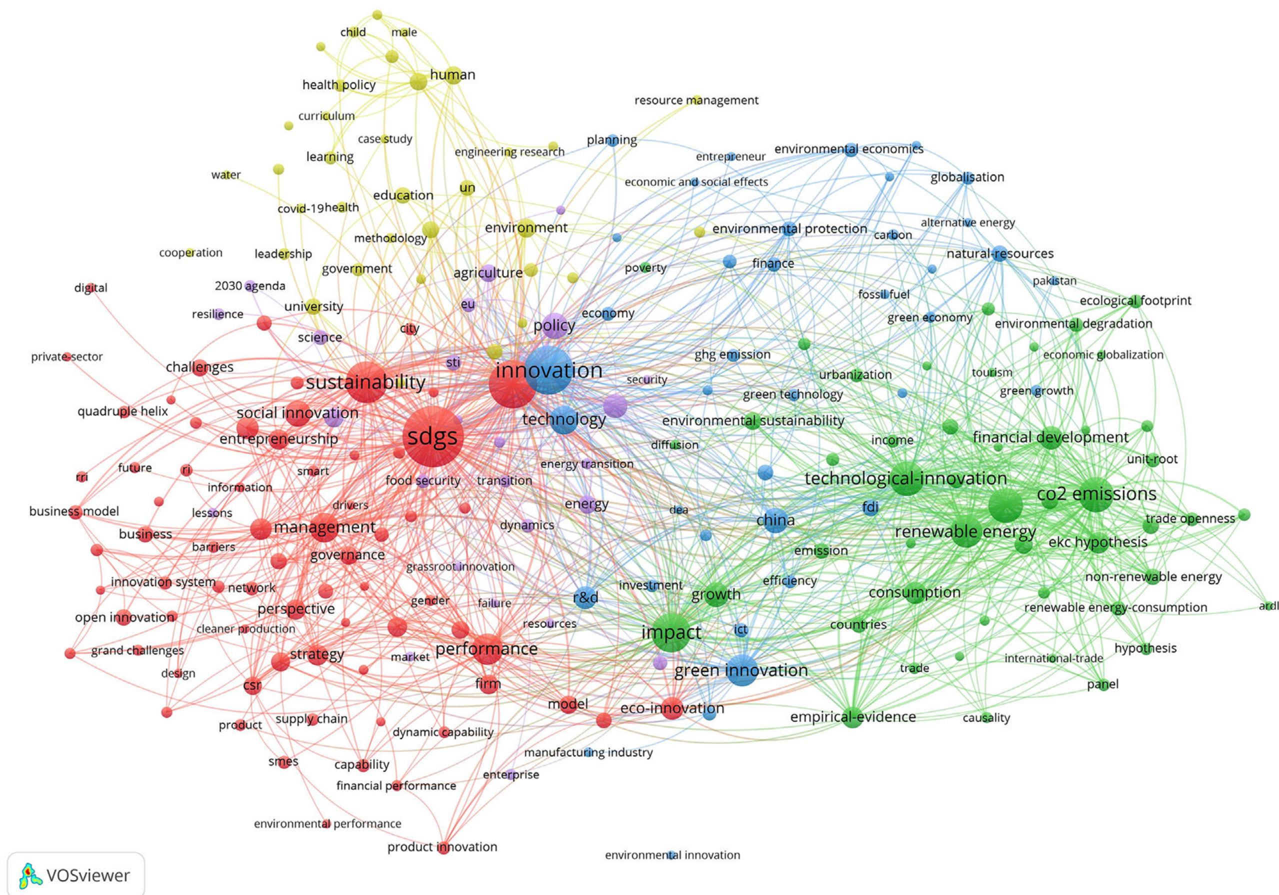

Fig. 3. Network visualisation of the sample database on innovations, STI and the SDGs.Sources: Figure created by the authors using VOSviewer 1.6.19

Which specific SDGs are detected in the existing literature on innovation, STI and SDGs?

A text file was prepared to identify the relevant SDG goals and targets within the sample database of 544 bibliometric records, including titles, abstracts and keywords. The SDG Mapper detected 122 SDG targets (out of 169) in the sample database.

Table 3 shows the 24 targets with innovation-related keywords that were identified by the SDG Mapper tool. When we compared these to our original list of 31 targets that we expected to find within the sample database, we found 18 matches (marked in bold). An examination of the sum of occurrences shows that researchers are most interested in SDG 8.2 (n = 514 occurrences), SDG 9.5 (n = 452), and SDG 7.2 (n = 353).

The relevance of goals and targets is represented by bubbles in Fig. 4. The size of the bubble is determined by the percentage of corresponding keywords detected (the ratio of the number of keywords relating to a single goal to the total number of keywords). The total number of detected keywords was 3656. Thus, SDG 8 (decent work and economic growth) is the most visible, with 1107 occurrences, followed in second and third places by SDG 9 (industry, innovation and infrastructure) and SDG 7 (affordable and clean energy), with 567 and 534 occurrences respectively.

SDG 8.2 (diversify, innovate and upgrade for economic productivity) is represented by the largest bubble, with “technolog innov” the most detected keyword, appearing 494 times in the sample database. The second most popular keyword was “renew energi”, with 282 occurrences, followed by “econom growth”, which appeared 167 times. The top ten keywords also include “green technolog” (n = 122 occurrences), “sti” (n = 60) and “r&d” (n = 59).

Fig. 5 shows the SDGs detected and their distribution across the 5Ps. The consolidation of the SDGs into the 5Ps supports efforts to gauge progress and underscores the fact that the SDGs are not a collection of isolated goals but, rather, closely interconnected.

The results of the SDG Mapper show that the Prosperity dimension, which includes SDG 7 (14.6 %), SDG 8 (30.3 %), SDG 9 (15.5 %), SDG 10 (reduced inequalities) (3.1 %) and SDG 11 (sustainable cities and economies) (3.1 %), accounts for approximately 67 % of all identified keywords. Thus, the majority of the publications in our database were devoted to economic aspects. The next most frequently occurring SDGs are those pertaining to the Planet dimension, including the environmental aspects of SDG 6 (clean water and sanitation) (1.1 %), SDG 12 (responsible consumption and production)(5.1 %), SDG 13 (climate action) (7.1 %), SDG 14 (life below water) (0.2 %) and SDG 15 (life on land) (5.3 %) which collectively account for 18.8 % of occurrences. The People dimension (11.8 %) ranks third, encompassing SDG 1 (no poverty) (1.8 %), SDG 2 (zero hunger) (3.1 %), SDG 3 (good health and well-being) (4.9 %), SDG 4 (quality education) (1.6 %) and SDG 5 (gender equality) (0.4 %), which together address equity and justice within public and private communities and national entities. SDG 17 (partnership for the goals), representing the Partnership dimension, is crucial in fostering innovation but was penultimate in the list of most frequently cited SDGs, with 1.9 %. The Peace dimension (SDG 16 – peace, justice and strong institutions) is mentioned in the fewest publications, accounting for only 0.9 % of mentions.

Role of innovation in achieving the SDGs

The text-mining technique identified concepts, that is, the most frequently appearing noun phrases in titles and abstracts. Noun

Table 3
21 SDG targets selected by innovation-related keywords.

5P	Goal	Target	Sum of occurrences	List_of_keys
People	SDG 1	**1.4**	4	properti right
	SDG 2	**2.3**	1	agricultur productivity
	SDG 2	2.4	15	sustain food product system, sustain agricultur, agroecolog, sustain food system
	SDG 2	**2.a**	9	agricultur research
	SDG 3	3.0	1	health research innov
	SDG 4	**4.4**	5	digit skill, technolog skill, vocat educ, new skill, e-learn
	SDG 4	4.a	1	school comput
	SDG 5	**5.b**	1	ict women
Prosperity	SDG 7	**7.1**	15	modern energi, afford energi, mini-grid, electr generat
	SDG 7	7.2	353	clean energi, renew energi, green energi, wind energi, solar energi, eco-friend energi, solar power, wind turbin
	SDG 7	**7.a**	5	clean energi technolog, financ clean energi
	SDG 8	**8.2**	514	technolog innov, technolog progress, innov growth, competit innov, innov competit, improv productivity
	SDG 8	**8.3**	169	entrepreneurship, support smes, capit market
	SDG 8	**8.10**	7	mobil money servic
	SDG 9	**9.0**	19	digit transform, digitalis
	SDG 9	**9.2**	16	sustain industri, manufactur industri, clean industri, creativ industri, sustain industrialis
	SDG 9	**9.4**	6	sustain industri process, clean technolog
	SDG 9	**9.5**	452	innov infrastructur, innov industri, industri innov, industri technolog, research develop, r&d, innov technolog, green technolog, foster innov, research innov, innov research, network research, facilit innov, scientif research, scienc technolog innov, sti
	SDG 9	**9.b**	1	develop countri technolog
Planet	SDG 12	**12.5**	70	recycl, reus resourc, circular economi
	SDG 13	13.2	37	climat chang polici, reduc greenhous gas emiss, reduc ghg, emiss reduct, reduc emiss, net zero emiss, reduc carbon emiss, emiss trade
Partnership	SDG 17	17.2	7	offici develop assist, oda
	SDG 17	**17.6**	33	partnership innov, share innov, share technolog, technolog transfer, collabor innov, partnership research, cooper research
	SDG 17	**17.7**	1	develop countri technolog

Source: the list of keywords was identified through the SDG Mapper tool.

phrases that appeared at least ten times were, in accordance with the default position, considered to meet the threshold for inclusion. Of the set of 13,163 noun phrases, 439 met this threshold. A crucial metric in text mining is the relevance score, which ranks words based on their importance in abstracts and titles. As might be expected, the most commonly occurring keywords were "sdgs" (n = 919 occurrences) and "innovation" (n = 892), but these were excluded as they formed part of the initial search query. Moreover, these terms had relevance scores of 0.02 and 0.21 respectively and, as argued by Van Eck and Altman (2023), excluding terms with low relevance scores – which are often generic terms and contribute minimal information – enhances the usefulness of a map. With these two terms hidden, the mapping was then rescored, resulting in 437 frequently occurring noun phrases which were selected for display on the map.

The VOSviewer text-mining network formed five clusters of varying sizes. The most prominent was a red cluster containing 200 items, while the smallest was a purple cluster with only 10 items.

Fig. 6 presents a network of distinct clusters of interconnected concepts precisely identified through co-occurrence frequencies. Each cluster, depicted in a different colour, showcases a different dimension of the role of innovation as discussed in the literature. We labelled the red cluster "Promoting Sustainable Development": it involves addressing issues in a way that supports the planet, benefits society and ensures long-term economic viability. This cluster highlights the interplay between government, universities and industry. The innovation-related keywords in this cluster are similar to those in the network map (Table 2).

The green cluster, "Driving Economic Growth", investigates "impact" on "economic growth" and the use of "renewable energy" and "technological innovation" to achieve environmental sustainability by reducing "CO2 emissions". This cluster emphasises leveraging "green innovation", "eco-innovation" and "environmental innovation" to drive economic growth while reducing environmental impact and addressing climate change. When supported by financial innovation, aspects such as "renewable energy" and "energy innovation" play a significant role in ensuring long-term sustainability.

The blue cluster, "Strengthening policy", is concerned with policies and initiatives that promote innovation and sustainability within specific geographic regions. The cluster also includes "methodology", "index" and "assessment", which refer to the development and adoption of the Agenda 2030 programme. The yellow cluster, "Enhancing enterprise performance", focuses on systematically examining data and evidence and utilising "models" and "theories" to understand "industry" and "firm performance", while the purple cluster brings together various keywords that were not grouped with other clusters.

Discussion

Our research has adopted a comprehensive approach to understanding the role of innovation and STI in achieving the SDGs. It provides a detailed and nuanced understanding of the intellectual structure by following a three-pronged approach, using the SDG Mapper, bibliometric analyses and text mining.

The co-occurrence analysis identified five clusters, the largest of which (the red cluster) is oriented around sustainable development. The inception of the Agenda 2030 prompted a surge in the number of scholarly papers published on all dimensions of sustainability, resulting in a substantial body of literature and significant contributions to the field (Khan, 2016; Schot & Steinmueller, 2018). The red cluster showcases the interconnections between the SDGs and ten specific types of innovation (Table 2), all of which support the three pillars of sustainability (environmental, social and economic). Specifically, eco-innovation is concerned with issues that reduce environmental impact and protect the planet (Albitar et al., 2023; Fatma & Haleem, 2023). Social innovation and responsible innovation, together with established methods such as open and grassroots innovation, are directed towards the social sphere (Ambati, 2019; Pansera & Sarkar, 2016). Finally, business model innovation, frugal innovation and product innovation support the economic pillar of sustainability, while business model innovation can contribute to sustainability by promoting local production and incorporating eco-friendly practices

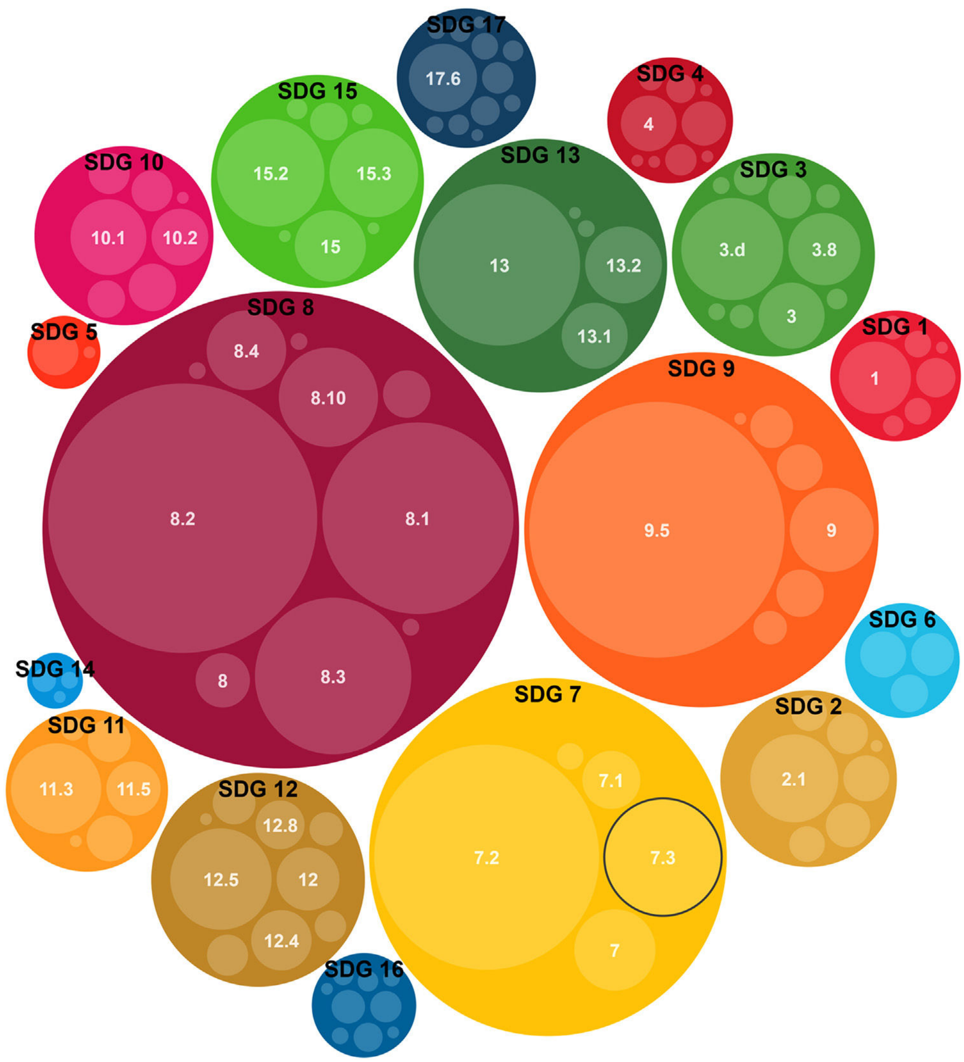

Fig. 4. SDG targets based on the percentage of corresponding detected keywords.Sources: Figure created by the authors using SDG Mapper tool

(Ciccullo et al., 2022). Thus, the network visualisations demonstrate strong links between sustainable development and innovation and show interconnectivity between all three pillars, indicating a promising avenue for further research in this area.

The text-mining analysis revealed four principal clusters within the focus of our study on the roles of innovation. These clusters highlight the role of innovation in promoting sustainable development (e.g. Cherednichenko et al., 2022; Wakunuma & Jiya, 2019), driving economic growth (e.g. Ahmad et al., 2020), enhancing enterprise performance (e.g. Yin & Yu, 2022) and strengthening policy (e.g. Schot & Steinmueller, 2018). Although significant clusters have formed around these four roles, scientists should not confine their efforts to these areas. Indeed, one area where further research would be fruitful is around the barriers to innovation in achieving the SDGs and the roles of different actors in overcoming these. While existing studies focus primarily on the positive effect of innovation on SDGs, it is crucial also to investigate the challenges presented by innovation and the strategies used to overcome them. This will provide a more balanced and comprehensive understanding of the role of innovation.

The term “sdgs” is arguably included by researchers to endorse their work by establishing a connection with sustainability and the Agenda 2030, as evidenced by its notably low relevance score of 0.02. In the search based on article titles, the term “innovation” received the relevance score of 0.21, although this is still low. Considering the small number of innovation-related keywords (Table 2), we can conclude that “innovation” is still used primarily to attract a broader readership.

We employed SDG mapping to accurately identify pertinent SDGs within the sample database. The SDG Mapper tool identified all 17 goals and 122 out of 169 targets. Our results indicate that a staggering 90 % of innovation-related keywords are linked to the Prosperity dimension (Table 3), with SDG 8 the most-researched strand. The other four dimensions received limited attention, highlighting that further research is needed in these areas. It is also essential to recognise the links between different SDGs and conduct comprehensive interdisciplinary research. Since the SDGs are interconnected, addressing one goal often has implications for others. Therefore, studying the interlinkages and potential synergies or trade-offs between different goals may contribute to the development of more effective and holistic strategies for achieving the SDGs.

We also found through the SDG mapping that “technological innovation” is the most frequently mentioned keyword. Technology – or, more specifically, access to technological knowledge – is one of the most significant barriers to innovation. The protection and preservation of scientific and technological knowledge by more developed countries can prevent other countries from catching up (Schot & Steinmueller, 2018). The promotion of equitable access to knowledge and technology is essential in reducing this barrier. One possible

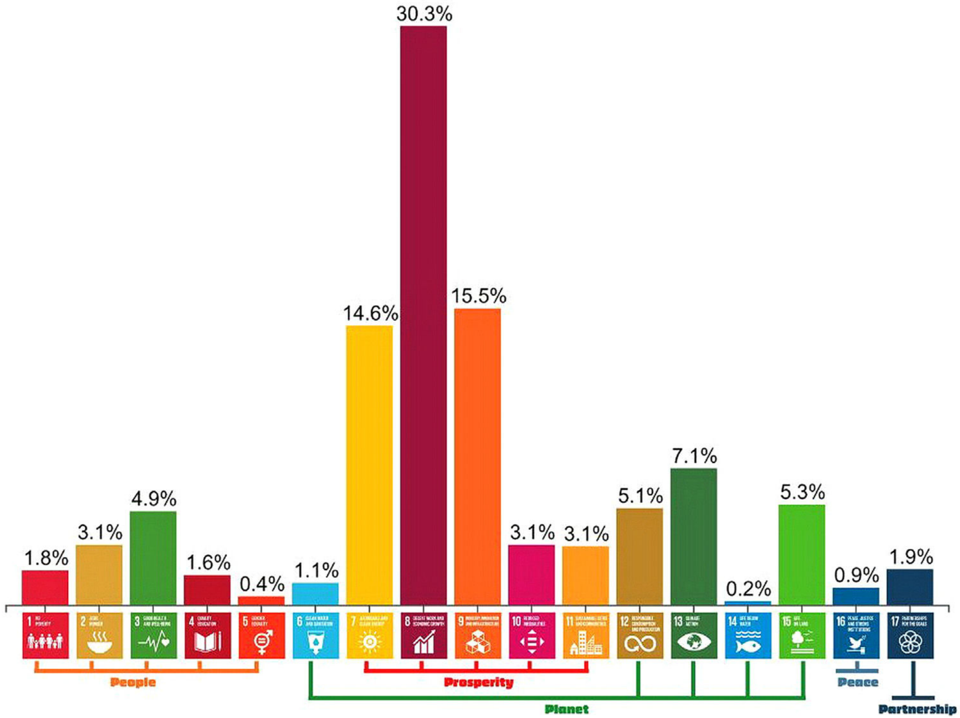

Fig. 5. . Relevant SDG goals according to 5Ps.Sources: Figure created by the authors using SDG Mapper tool

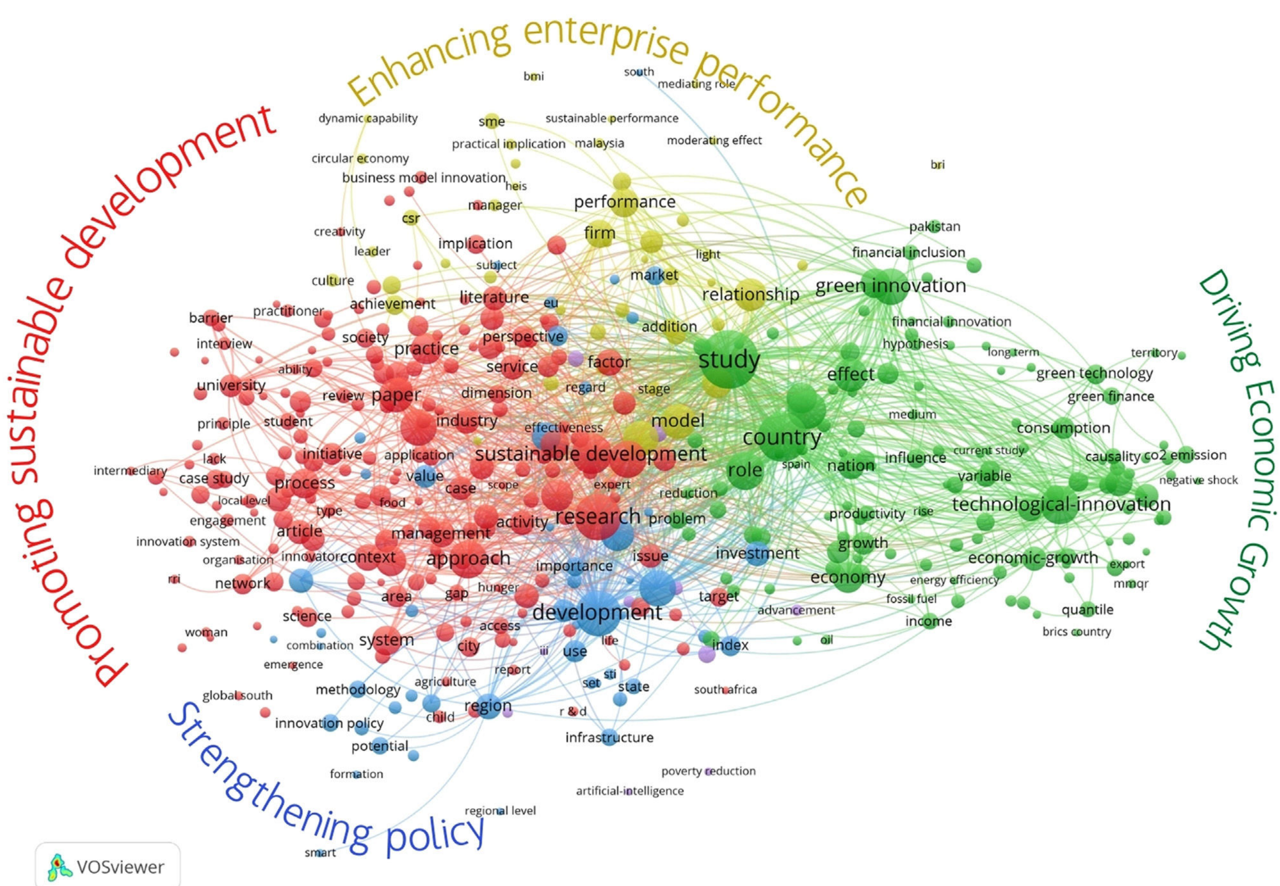

Fig. 6. Text-mining visualisation labelled by general topics.Sources: Figure created by the authors using VOSviewer 1.6.19

means of facilitating knowledge transfer is through the partnership dimension supported by TFM, which can address barriers to STI by providing access to critical resources, infrastructure and financing and by sharing R&D capabilities (Choi & Cho, 2023; Lee et al., 2021; Walsh et al., 2020). The lack of analysis of supportive frameworks such as the TFM is a clear research gap. These frameworks may play a crucial role in incorporating multiple stakeholder perspectives and considering trade-offs between economic, social and environmental sustainability.

Conclusion

As the Agenda 2030 programme approaches its midpoint, scientists are relying increasingly on innovative solutions to bridge the remaining gap towards achieving the UN's SDGs. This was the original impetus for our study. The remarkable surge in publications between 2015 and 2023 enabled us to include 544 articles in our sample database, sourced from the Scopus and WOS databases.

Our study employed bibliometric analysis to investigate the relationship between innovation, STI and the SDGs. Through this process, we gained insights into the current state of knowledge, systematised the intellectual structure of innovation and STI to achieve the SDGs and identified areas for further research. Density visualisation suggests that STI is under-researched. The network visualisation showed five clusters: the SDGs and the three pillars of innovation (red cluster), environmental aspects (blue cluster), technological innovation (green cluster), education and health topics (yellow cluster), transition and STI (purple cluster).

The SDG Mapper detected 122 SDG targets in the sample database. SDG 8 was the most studied, with “technological innovation” the most frequently observed term. The SDG Mapper revealed that most occurrences were associated with the prosperity dimension, including SDGs 7−11.

The text-mining technique identified five clusters, four of which were relevant for understanding the role of innovation in achieving the SDGs. The red cluster embodies the vital task of fostering sustainable development, encompassing a broad spectrum of innovative practices that pertain to the social, economic and environmental pillars. The key innovations most closely connected with achieving the SDGs include social innovation, frugal innovation, open innovation, business model innovation and digital innovation. The green cluster emphasises technological innovation, which sees as the driving force behind economic growth; meanwhile, the blue cluster focuses on policies and initiatives that promote innovation and, finally, the yellow cluster indicates that innovation enhances business performance.

Contributions

Previous studies have explored the role of innovation in various contexts and specific types of innovation (Anwar et al., 2022; Khan et al., 2022; Schroeder et al., 2019; Wang et al., 2022). We aimed to add value to the existing literature by examining the broader contribution of innovations in achieving the SDGs.

First, by explicitly focusing on three keywords − “innovation”, “sti” and “sdgs” − we were able to gain a comprehensive overview of the intellectual structure of the existing literature, which we found to be organised into thematic clusters around the roles of innovation in achieving the SDGs.

Second, our study highlights the explicit connections between innovation and specific SDGs. Using the SDG Mapper tool, we identified 1742 keywords, showing the domains where innovation is closely intertwined with the SDGs. However, the relationship between innovation and the SDGs remains underexplored in some significant areas, including gender equality (SDG 5), peace (SDG 16) and partnership (SDG 17), presenting many opportunities for further research. This valuable information may guide future research endeavours and policy-making initiatives, directing attention towards specific SDGs and target areas where innovation can have the most substantial influence.

Thirdly, our study aimed to identify research gaps and propose potential avenues for future investigation. By emphasising the need for more comprehensive literature on STI and identifying research gaps related to the partnership dimension and TFM, we highlight valuable directions for researchers to explore in the future. These insights not only contribute to the existing knowledge base on innovation and the SDGs but also encourage further enquiry into critical areas that warrant attention, enabling a deeper comprehension of the available studies and their interconnectedness. Our findings suggest that scholars should adopt a broad perspective when approaching innovation, as it intersects with various research domains that play a crucial role in fostering a holistic understanding and offer the potential for engaging studies.

Limitations

It is essential to acknowledge that our analysis has certain limitations: the first relates to the choice of keywords. While we used a comprehensive set of keywords, the possibility remains that some relevant studies were omitted. Expanding the set of keywords or using alternative search strategies could help capture a broader range of literature on innovations and the SDGs.

The second limitation pertains to the use of specific databases and exclusion criteria. By focusing on the Scopus and WOS databases and excluding certain document types, relevant studies may have been missed.

The third limitation relates to the methodology employed in our study. While we used three interrelated methods (co-occurrence analysis, SDG mapping and text-mining), alternative methodologies exploring different approaches, such as qualitative content analysis, may provide additional insights and perspectives.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Gulnara Dzhunushalieva: Methodology, Software, Visualization, Writing − original draft. **Ramona Teuber:** Conceptualization, Writing − review & editing.

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