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# Decoding sustainable entrepreneurship current research and future direction through application of machine learning-based structured topic modeling on intellectual corpus

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## Abstract

This study leverages structured topic modeling (STM) to decode the expansive intellectual corpus on sustainable entrepreneurship, utilizing a dataset of 363 peer-reviewed articles from Scopus over a decade. Focused on "sustainable entrepreneurship" and related terms, the STM method integrated document-specific metadata to enhance the analysis of thematic developments. The findings revealed ten distinct topics, such as innovation in firm performance, sustainability in business models, and the role of education in sustainable intentions, highlighting the interplay between these themes and their evolution. This research identifies key thematic areas and examines the influence of source titles and publication years on topic prevalence, indicating shifts in academic focus and identifying emerging trends. The study's implications suggest integrating sustainability into core business and educational strategies, enhancing the understanding of sustainable entrepreneurship's dynamic nature, and providing a foundation for future scholarly and practical efforts.

**Keywords** Sustainable entrepreneurship · Machine learning · Structure topic modeling · Future

## Résumé

Cette étude s'appuie sur la modélisation structurée des sujets (STM) pour décoder le vaste corpus intellectuel sur l'entrepreneuriat durable, en utilisant un ensemble

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de données de 363 articles évalués par des pairs provenant de Scopus sur une décennie. Axée sur l' entrepreneuriat durable» et les termes connexes, la méthode STM a intégré des métadonnées spécifiques aux documents afin d'améliorer l'analyse des développements thématiques. Les résultats ont révélé dix sujets distincts, tels que l'innovation dans les performances des entreprises, la durabilité dans les modèles d'entreprise et le rôle de l'éducation dans les intentions durables, soulignant l'interaction entre ces thèmes et leur évolution. Cette recherche identifie des domaines thématiques clés et examine l'influence des titres des sources et des années de publication sur la prévalence des sujets, indiquant des changements dans l'orientation académique et identifiant les tendances émergentes. Les implications de l'étude suggèrent d'intégrer la durabilité dans les stratégies commerciales et éducatives de base, d'améliorer la compréhension de la nature dynamique de l'entrepreneuriat durable et de fournir une base pour les futurs efforts scientifiques et pratiques.

**Mots-clés** Entrepreneuriat durable · Apprentissage automatique · Modélisation structurelle et thématique · Avenir

**JEL Classification** C63 · L26 · L31 · Q56 · C63 · L26 · L31 · Q56

**Codes JEL** C63 · L26 · L31 · Q56

## Summary highlights

*Contributions*: Applying machine learning-based STM with integrated metadata, this study provides a dynamic analysis of sustainable entrepreneurship discourse. It reveals ten distinct thematic areas and the influence of publication year and source on their development, providing a comprehensive understanding of the landscape that can guide future research.

*Research question*: How have the thematic structures and interrelationships in sustainable entrepreneurship literature evolved over the past decade, and to what extent have publication-related factors (e.g., year and source) influenced the emergence, prominence, and interconnection of these themes?

*Basic method*: This study uses machine learning-based structured topic modeling (STM), incorporating metadata for enhanced topic analysis.

*Source of information/data*: Using Scopus, a comprehensive database of peer-reviewed literature, we compiled a dataset of 363 articles for in-depth analysis of sustainable entrepreneurship via STM.

*Results*: This research reveals the increasing integration of digital transformation and green entrepreneurship within sustainable entrepreneurship, mirroring broader societal changes. Analysis of source titles and publication years highlights a growing scholarly focus on embedding sustainability in business and education.

*Limitations*: The study's focus on journal articles indexed in Scopus databases may exclude some studies from other sources.

*Practical implications for management and recommendations*: Entrepreneurs should integrate sustainability as a core business principle for long-term value and competitive advantage, while entrepreneurship institutions provide the necessary tools, resources, and training to help startups and small enterprises do the same.

*Recommendations for future research*: This study enhances bibliometric analysis through STM with metadata integration and recommends future research on emerging themes like digital transformation, green entrepreneurship, and sustainable education using advanced techniques.

## Introduction

Sustainable entrepreneurship, which integrates environmental stewardship and social responsibility with the pursuit of economic viability, has emerged as an increasingly prominent field of research and practice (Muñoz and Cohen 2018; Vedula et al. 2022). This domain extends beyond the traditional boundaries of corporate social responsibility, evolving into a strategic lens through which entrepreneurial ventures are envisioned, launched, and managed to achieve enduring value creation for societies and the planet (Cohen and Winn 2007; Dean and McMullen, 2007). The theoretical foundation of sustainable entrepreneurship draw from multiple frameworks, including the triple bottom line (Elkington 1998), stakeholder theory (Freeman 2010), and the resource-based view of the firm (Barney 1991), as well as the entrepreneurship literature that emphasizes opportunity recognition, innovation, and firm-level adaptation (Pacheco et al. 2010; Shepherd and Patzelt 2011). These conceptual foundations enumerate that sustainable entrepreneurship involves identifying, evaluating, and exploiting opportunities that generate both economic returns and positive environmental and social impacts, thus bridging the gap between conventional entrepreneurial practices and broader sustainable development goals (Schaltegger and Wagner 2011).

Over the last decade, academic research has increasingly focused on the various facets of sustainable entrepreneurship, exploring themes such as green innovation, eco-venture creation, socially responsible business models, and ecosystem development (Anand et al. 2021; Moya-Clemente et al. 2021; Contreras Cruz et al. 2024). Bibliometric analyses have illuminated the growing complexity and interdisciplinary nature of this field (Alkathiri et al. 2024; Arya et al. 2024; Gupta et al. 2024; Ribeiro and Leitão 2024), revealing shifts in terminology, evolving research clusters, and a gradual convergence of previously disparate themes (Di Vaio et al. 2022; Reuther et al. 2023; Bonfanti et al. 2024). Yet, while these studies have provided essential roadmaps, they often rely on conventional analytical approaches that cannot fully capture the latent structures, interdependencies, and evolving trajectories within extensive scholarly corpora. The need for more advanced, data-driven, and adaptive analytical methods has become increasingly evident, as these methods can shed light on how sustainable entrepreneurship concepts evolve under the influence of temporal, contextual, and bibliometric factors (Roberts et al. 2013; Bai et al. 2021; Martinez et al. 2022).

In response to this recognized gap, the present study leverages machine learning-based structured topic modeling (STM) to examine how sustainable entrepreneurship research themes have evolved over 10 years. Unlike traditional topic modeling techniques, STM integrates document-level metadata (e.g., publication year, source) directly into the topic inference process, enabling a more nuanced analysis that reveals not only what themes are present but also how they vary in prominence and interrelation depending on contextual factors, including metadata as covariates aligns with the theoretical premise that knowledge production is inherently influenced by temporal, institutional, and environmental conditions, thereby reinforcing the dynamic, context-sensitive nature of sustainable entrepreneurship research. This methodological advancement seeks to address the literature's call for tools that can capture the fluidity of the field and provide,more explicit evidence of how external drivers shape the conceptual undercurrents of sustainability-oriented entrepreneurship scholarship.

Building upon these theoretical and methodological foundations, the central research question (RQ) guiding this study is: How have the thematic structures and interrelationships in sustainable entrepreneurship literature evolved over the past decade, and to what extent have publication-related factors (e.g., year and source) influenced the emergence, prominence, and interconnection of these themes? In exploring this question, we hypothesize the following:

- H1: Over time, the number and complexity of thematic clusters identified in sustainable entrepreneurship literature have increased, reflecting an evolving and more integrated conceptual landscape that merges previously distinct areas (Pacheco et al. 2010; Shepherd and Patzelt 2011).
- H2: Thematic clusters will exhibit varying degrees of correlation and interconnection, highlighting that sustainable entrepreneurship is not a static compilation of topics but a dynamically evolving field shaped by theoretical refinements, socio-economic conditions, and policy directives.

This study employs a systematic methodological approach to address the RQ and test these hypotheses. We begin by constructing a dataset from Scopus, focusing on scholarly articles published over a decade that include key terms such as "sustainable entrepreneur," "green entrepreneur," "eco entrepreneurship," and "sustainable venture." This search yielded 363 relevant articles, ensuring both topical relevance and sufficient coverage to represents the field's evolution accurately represents the field's evolution accurately represent the field's evolution. We then applied term frequency-inverse document frequency (TF-IDF) preprocessing to refine our corpus, suppressing less informative terms and amplifying key conceptual signifiers. Next, we implemented STM to incorporate metadata, allowing a direct investigation of how external factors shape thematic trajectories within the literature. Through STM's nuanced modeling capabilities, we identified ten primary topics that cover innovation and entrepreneurship in firm performance, sustainability in business models and social entrepreneurship, the development of innovation ecosystems, and the emergence of green entrepreneurship and digital transformations in sustainable ventures.

The findings of our STM analysis uncovered dynamic inter-topic correlations, shifts in thematic prominence over time, and evolving roles of different publication sources. Five notable trends emerged: (1) the progressive integration of digital transformations within sustainable practices; (2) the rising focus on green entrepreneurship and environmental impact; (3) the growing significance of sustainable educational frameworks and entrepreneurial intentions; (4) the adaptation of economic models in the context of sustainable development, especially among SMEs; and (5) the consistent push towards resilience and strategic sustainability across business ecosystems.

This study on sustainable entrepreneurship through machine learning-based STM has provided several critical contributions to the field. First, it has advanced the methodological frontier by integrating metadata into the analysis process, enabling a more systematic examination of thematic evolution within the academic discourse on sustainability in entrepreneurship. This technique has allowed for a particular exploration of how various factors, such as publication year and source, impact the prominence and development of specific themes, offering a dynamic view beyond traditional static analyses. Second, the research has contributed significantly to the literature by identifying and portraying ten thematic areas within sustainable entrepreneurship. This categorization not only clarifies the structure and focus of the field but also highlights inter-topic relationships and their changes over time, providing a comprehensive understanding of the landscape that can guide future research, policy-making, and entrepreneurial practice in sustainability. Third, the study has practical implications by revealing trends and shifts in the academic treatment of sustainable entrepreneurship over a decade. These insights are crucial for academic stakeholders, policymakers, and entrepreneurs as they reflect broader socio-economic shifts towards sustainability and can influence strategic decisions in research and practice. This work thus not only enriches academic discussions but also serves as a strategic guide for embedding sustainability more profoundly into business and educational strategies.

The subsequent structure of the document is organized as follows: the "Topic modeling" section provides an in-depth examination of topic modeling, exploring several methodologies with a particular focus on STM. The "Method" section describes the methodological approach, detailing the data collection, preparation, and processing phases. The "Results" section presents the descriptive results and findings derived from STM. The "Discussion on result, five major trends, and implications" section interprets these findings, aligning them with five central themes. Finally, the "Conclusion and future research" section concludes the study, discussing its broader implications and identifying potential directions for future research.

## Topic modeling

Topic modeling encompasses a range of machine learning-driven text-mining methods designed to uncover the underlying thematic structure of textual corpora. Its use in reviewing scientific literature has been growing, as academic articles—being inherently unstructured—lend themselves well to analysis through topic modeling (Roberts et al. 2014). These models efficiently and accurately pinpoint core themes

and trends within extensive data collection. Consequently, topic modeling has become for researchers examining thematic patterns and developments across various academic fields. Among the array of topic modeling approaches, latent Dirichlet allocation (LDA) and STM are commonly employed in such analytical investigations (Bai et al. 2021).

### Latent Dirichlet allocation model

LDA represents the prevalent methodology for topic modeling in document analysis. This approach posits that documents and their constituent words emerge from a generative probabilistic framework, as delineated by Blei et al. (2003). In this model, $d \in \{1, 2, \ldots, D\}$ indexes documents, $k \in \{1, 2, \ldots, K\}$ indexes topics (with K set by the researcher), and $n \in \{1, 2, \ldots, N\}$ indexes word positions in each document. As described by Blei et al. (2003), the generative process for producing a document involves:

- The number of words in document $d$ ($Nd$) is drawn from a Poisson distribution.
- Each document $d$ is associated with a topic distribution $\theta d$ drawn from a Dirichlet distribution governed by $\alpha$.
- Each topic $k$ has an associated word distribution $\beta k$, drawn from a Dirichlet distribution with parameter $\eta$.
- For each word position $n$ in document $d$, a topic assignment $Zd,n$ is selected from a multinomial distribution defined by $\theta d$. Then, the actual word $Wd,n$ is chosen from a multinomial distribution determined by $\beta k$ associated with $Zd,n$.
- The matrices $\theta d$ and $\beta k$ are central to LDA, as $\theta d$ indicates how likely each topic is to appear in a given document, and $\beta k$ reveals the most characteristic terms of each topic.

Despite its widespread use, LDA has notable constraints. It does not account for how external covariates might influence the representation of topics or words in documents, and it assumes that topics are independent, neglecting potential correlations among them. To adress these drawbacks, various extended models have been developed. In this study, we employ STM (Roberts et al. 2013) to address the limitations inherent in LDA.

### Structure topic modeling

The STM builds on LDA by allowing topics to correlate, a feature not supported by LDA's reliance on the Dirichlet distribution. Unlike LDA's static framework, STM incorporates document-level covariates into topical prevalence parameter $\theta d$ and the topical content parameters $\beta k$, applying a generalized linear model to capture these relationships. As a result, the model dynamically reflects how document characteristics influence the composition and distribution of topics.

Expounded by Roberts et al. (2014), STM's distinctive attributes include the treatment of $\theta_d$ as a random variable derived from a log-normal distribution,

wherein covariate values modulate the distribution's parameters. Conversely, $\beta_k$ is configured to adhere to a multinomial logit model, signifying an intricate method for determining word prevalence within topics. This model intricately weaves together topic influences, document covariates, and their interactions in determining the distribution of words across topics.

Roberts et al. (2013b) provide a mathematical formulation for this relationship, where *vv* symbolizes individual words within a designated vocabulary and *mvmv* denotes the baseline log frequency of word *vv*. Adjustments for topic and covariate values are encapsulated by κκ, leading to a definition of the per-corpus topic-word distribution $\beta_{d,,v}$ as proportional to

$$\beta_{d,k,v} \propto \exp\left(m_v, \kappa_v^{\cdot,k} + \kappa_v^{y,\cdot} + \kappa_v^{y,k}\right)$$

This formulation explains a marked departure from LDA, offering a richer, more precise understanding of topic distribution influenced by external covariates.

The divergences between LDA and STM are further elucidated through a comparative illustration of their respective plate notation diagrams, as indicated in Fig. 1 by Roberts et al. The following visual representation underscores the foundational and methodological distinctions between the two models, highlighting STM's enhanced capacity for capturing the complexities of topic-covariate interactions.

## Method

### Data identification, refining, and extraction

Data identification and retrieval for our study on sustainable entrepreneurship was conducted using Scopus, a comprehensive database widely recognized for its extensive coverage of peer-reviewed literature suitable for quantitative analysis (Qadri et al. 2022). The decision to utilize Scopus as our primary metadata source was informed by its broad scope, encompassing over 20,000 peer-reviewed active titles, and its capacity to support detailed bibliometric analyses. This choice reflects a preference for depth and quality of coverage, acknowledging the platform's advantages in facilitating particular scholarly research over alternatives like Web of Science and Google Scholar (Qadri et al. 2024).

Scopus is particularly valued for its inclusion in journal articles (Ali and Aysan 2024), conference proceedings, and book series, offering a richer dataset for comprehensive bibliometric studies. Its extensive use in prior bibliometric research underlines its suitability and effectiveness for such analyses (García-Lillo et al. 2019; Rialp et al. 2019; Baker et al. 2020; Das et al. 2023; Tahir et al. 2023).

On March 30, 2024, a search for "sustainable entrepreneur" OR "green entrepreneur" OR "sustainable entrepreneurship" OR "eco entrepreneurship" OR "environmental entrepreneurship" OR "entrepreneurial innovation" OR "sustainable venture" in titles only within Scopus yielded 529 documents. The set period was 2014–2024. After refining our search criteria to include only articles and excluding other document types to ensure consistency and relevance to our research focus, the

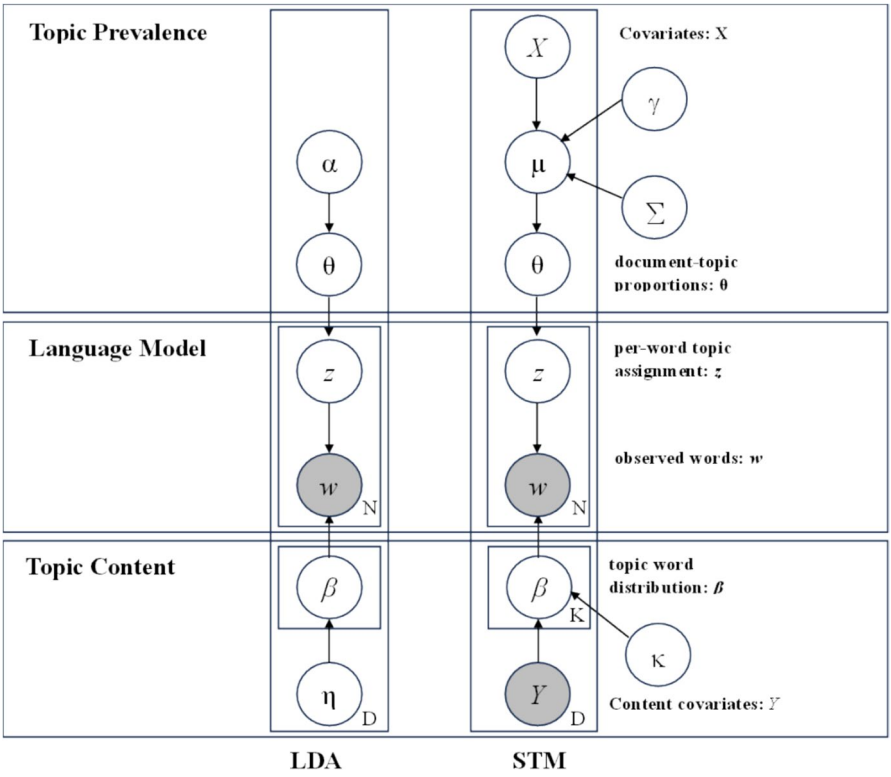


**Fig. 1** Plate notation of LDA and STM. Source: Modified and taken from Bai et al. (2021)

dataset was narrowed down to 363 documents. These selected publications, comprising articles only, formed the basis of our analysis. The steps of the research process flow are illustrated in Fig. 2.

### Pre-processing of text and metadata

Based on the data extracted from Scopus, we carefully compiled a text corpus that included the title, abstract, keywords, and publication year of every research article published. We also checked publication source impact on the prominence of the topics by adding source titles in our corpus. We eliminated copyright information, publisher names, non-English words, and special characters, such as currency symbols and punctuation, to pre-process the text for analysis. In the end phase of the pre-analysis, following the study by Bai et al. (2021), the term frequency-inverse document frequency (TF-IDF) metric is employed to evaluate the relative significance of each term within the corpus. The utility of frequent terms is often limited, as their prevalence across documents may not contribute meaningful insight. Specifically, specific terms standard in scientific discourse, such as "study" and "paper," are deemed to hold minimal informational value for topic modeling objectives and

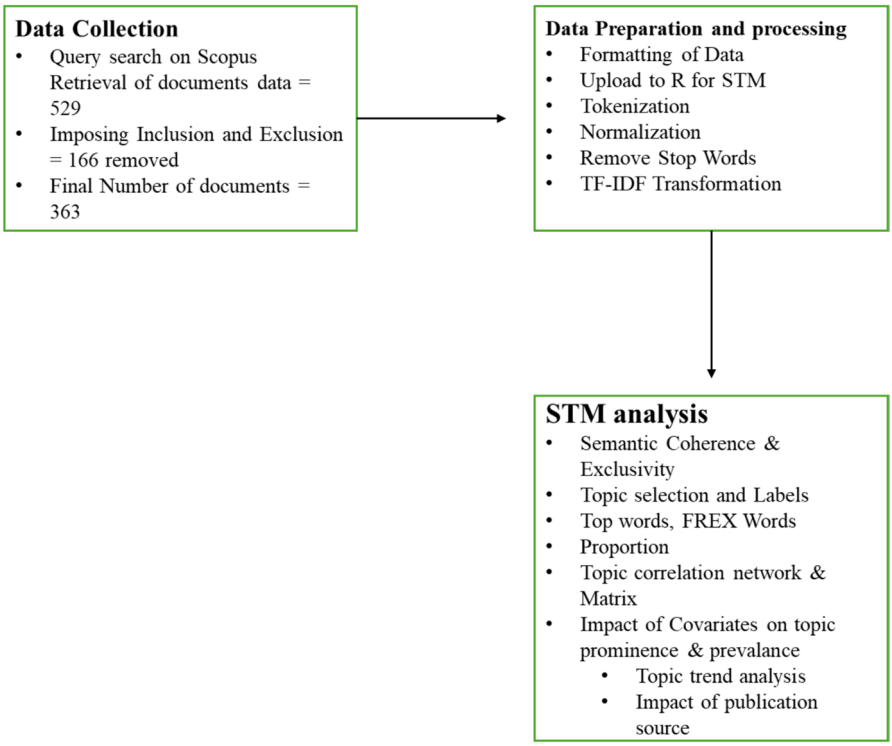


**Fig. 2** Research process flow. Source: Authors' own construction

are thus excluded from subsequent analyses. This research employs a TF-IDF transformation to refine the word corpus, effectively diminishing the weight of terms that appear across numerous documents while accentuating those that, despite their infrequency, possess a distinct capacity to delineate documents. This process, articulated by Jiang et al. (2016), involves computing the TF-IDF scores for all terms, which are then ranked according to their values. A critical examination of terms with lower TF-IDF scores facilitates the establishment of a threshold; terms falling below this threshold are eliminated, and the term frequencies of the remaining corpus are recalculated. The TF-IDF metric encompasses two primary components: TF and IDF. The former quantifies a term's occurrence frequency, adjusted for document length to mitigate the inherent bias towards longer documents. Let $D$ represent the total number of documents and V, the total number of unique terms in the corpus. The TF value, $TF_{ij}$, for term $i$th in document $j$th is defined as:

$$TF_{ij} = C_{ij}/N_j$$

Here, $C_{ij}$ is the occurrence count of term $i$ in document $j$, and $N_j$ denotes the total term count in document $j$.

Conversely, the IDF component assesses a term's exclusivity across the corpus. Terms ubiquitous across numerous documents, such as "model" or "study" within

academic papers, are deemed less significant. The IDF formula penalizes these standard terms as follows:

$$IDF_i = \log_2\left(D/D_i\right)$$

where $IDF_i$ is the IDF value for term $i$, and $D_i$ is the number of documents containing term $i$th. Subsequently, the aggregate TF value for term $i$ across the corpus is obtained by amalgamating the TF and IDF values, thereby normalizing term frequencies:

$$TF_i = \sum_{j=1}^{D} TF_{ij} * IDF_i$$

In this investigation, a TF-IDF threshold is meticulously set at 0.1736 (the 80th percentile), beyond which terms are considered sufficiently distinctive for inclusion in the analysis. This methodology leverages the STM package for further examination. Finally, we conducted an empirical investigation by testing different numbers of topics, ranging from 5 to 30, to determine the most suitable number for our research, which is also in line with previous research (Sharma et al. 2021; Baker et al. 2021). The selection favored ten subjects based on maximizing the average held-out likelihood from the model, indicating the most representative thematic structure.

## Results

### Descriptive results

The descriptive statistics in Table 1 sum up the scholarly landscape of sustainable entrepreneurship research from 2014 to 2024, comprising data from 186 sources, including journals and books, amounting to 363 documents. This body of work is growing at an annual rate of 9.39%, reflecting a steady increase in academic interest and output in this field. The documents have an average age of 3.53 years, suggesting a relatively recent and current collection of research. On average, each document is cited 27.51 times, indicating a robust engagement with and acknowledgment of this work within the academic community. The documents are underpinned by a substantial number of Keywords Plus (753) and Author's Keywords (1159), highlighting a rich and diverse terminological footprint and denoting a wide array of research focuses within the domain. A total of 986 authors have contributed to this corpus, with 44 authors having single-authored documents, which, in total, accounts for 45 single-authored works. Collaboration is significant, with an average of 3.01 co-authors per document and 31.68% of the documents featuring international co-authorships, demonstrating a strong global collaborative spirit in the research of sustainable entrepreneurship.

The line graph in Fig. 3 depicts the trail of document production related to sustainable entrepreneurship as cataloged within the Scopus database, charting an

**Table 1** Data summary

| Description | Results |
|---|---|
| Main information about data | |
| Timespan | 2014:2024 |
| Sources (journals, books, etc.) | 186 |
| Documents | 363 |
| Annual growth rate % | 9.39 |
| Document average age | 3.53 |
| Average citations per doc | 27.51 |
| References | 1 |
| Document contents | |
| Keywords Plus (ID) | 753 |
| Author's Keywords (DE) | 1159 |
| Authors | |
| Authors | 986 |
| Authors of single-authored docs | 44 |
| Authors collaboration | |
| Single-authored docs | 45 |
| Co-authors per doc | 3.01 |
| International co-authorships % | 31.68 |
| Document types | |
| Article | 363 |

Source: author's own results

evident growth trend from 2014 through a projection into 2024. The initial years show a modest output, which begins to ascend around 2016, marking an inflection point toward a more robust scholarly output. The apex observed in 2021 to 2023 suggests a peak in literary interest. The projection into 2024 implies an anticipation of the growing trend. This projection is not without foundation; it reflects the rising urgency of integrating sustainability principles in business practice, a response to the increasing environmental, social, and governance (ESG) pressures from consumers, regulators, and investors alike. As businesses and economies confront the imperatives of climate change, resource scarcity, and social inequity, the pertinence of sustainable entrepreneurship is underscored, positioning it as a critical domain within both scholarly and practical spheres.

Figure 4 illustrates the annual scholarly output on sustainable entrepreneurship from various countries, as recorded over a decade-long span leading up to projections for 2024. The lines, each representing a different country, trace the volume of articles produced each year, with all countries starting from a relatively similar baseline in 2014. Over time, the graph shows a general upward trend, reflecting a global increase in research and publication in sustainable entrepreneurship. This upward trajectory can be attributed to the growing international consensus on the importance of sustainability in business practices, driven by environmental concerns, social shifts, and a heightened awareness of the economic benefits of sustainable practices. China, represented by the topmost line, displays a remarkable

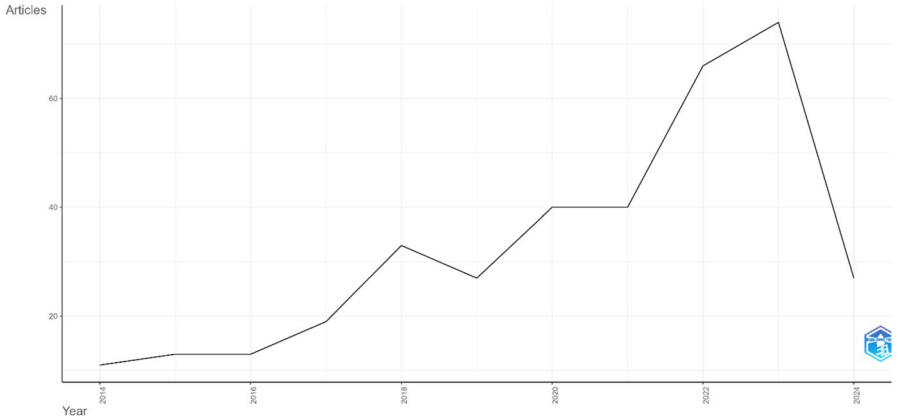


**Fig. 3** Annual production of documents. Source: Authors' own

surge, particularly noticeable from 2020 onwards, which could indicate the country's focused investment in sustainability as a strategic innovation area. This might also mirror China's broader economic and industrial policies prioritizing sustainable growth. Other countries, such as the USA and the UK, also show significant growth, sustaining their traditional roles as strong contributors to global research. However, their trajectories, while still on the rise, are more gradual than China's, possibly reflecting the established nature of sustainable entrepreneurship within their academic communities. In contrast, the remaining countries demonstrate varying degrees of increment, some with steeper slopes than others, suggesting a differential national prioritization and resource allocation to sustainability research.

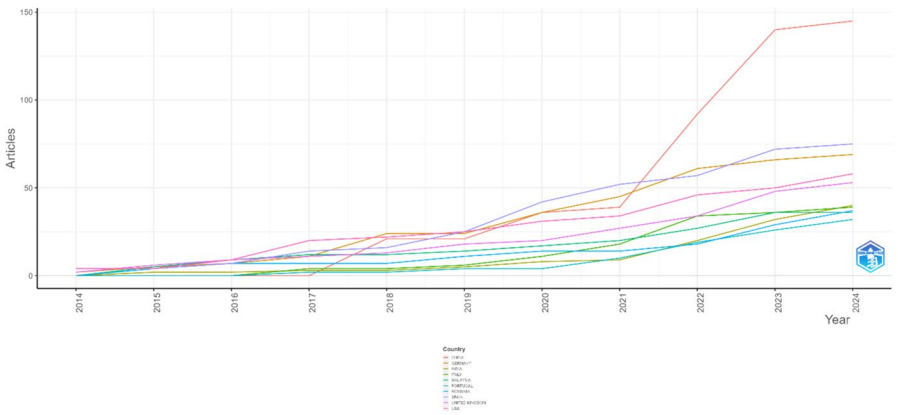


**Fig. 4** Top 10 countries as per contribution. Source: Authors' own results

### STM results

Table 2 delineates the categorization of the top ten topics, as derived through applying STM, along with the associated top words and FREX words for each topic. Concurrently, Fig. 5 depicts word clouds that visually represent the predominant words across these ten topics. The subsequent analysis provides a detailed exposition of each topic, informed by the insights from Table 1 and Fig. 1. Topic 1, "The Role of Innovation and Entrepreneurship in Firm Performance," delves into the symbiosis between innovative approaches and entrepreneurial ventures, highlighting their collective impact on a firm's success. This area explores the multifaceted influences of innovation and entrepreneurship on business outcomes, underlined by terms such as "Innovation," "Entrepreneurship," "Performance," and "Impact." Including "Hightech" and "Imitation" among FREX words points to a focused examination of technological advancements and strategic adaptation to enhance competitive advantage and market presence. Topic 2, "Sustainability in Business Models and Social Entrepreneurship," centers around integrating sustainability principles with entrepreneurial initiatives. The discourse is framed by keywords like "Sustainability," "Business," and "Social," emphasizing the pursuit of environmental and social objectives alongside economic goals. FREX terms "Risk" and "Bioeconomy" reflect specific challenges and pathways in crafting business models that contribute positively to sustainable development, spotlighting the innovative edge required to tackle ecological issues and societal needs. Topic 3, "Developing Innovation Ecosystems in Entrepreneurship," investigates the creation and nurturing of conducive environments for innovation within entrepreneurial landscapes. Terms like "Ecosystem" and "Capability" are pivotal, pointing to innovation ecosystems' systemic and dynamic nature. FREX words, including "Region" and "Knowledge-intensive," delve into how geographical, cultural, and knowledge-based factors interplay to cultivate rich, innovative ecosystems, emphasizing stakeholder collaboration and regional dynamics. Topic 4, "Sustainable Development Ventures and the Environment in Entrepreneurship," engages with the interplay between entrepreneurial ventures and environmental sustainability. This theme employs "Venture," "Environment," and "Sustainability" as critical lexicons, focusing on entrepreneurial projects with environmental consciousness at their core. The FREX terms "Bibliometric" and "Legitimacy" suggest an analytical lens on how such ventures are conceptualized and validated within the entrepreneurial domain, with a clear focus on sustainability. Topic 5, "Economic Development Through Sustainable Entrepreneurship," connects sustainability objectives and economic growth mechanisms. "Crowdfunding" and "SDGs" among FREX words signal diverse global frameworks and financing models supporting sustainable ventures. This thematic area highlights the importance of aligning entrepreneurial activities with global sustainability goals, emphasizing the role of innovation and cross-sector collaboration in driving economic development. Topic 6, "Environmental Quality Management and Development in Entrepreneurship," merges environmental stewardship with entrepreneurial management practices. The lexicon, featuring "Quality," "Management," and "Environment," reflects a commitment to incorporating environmental considerations into business operations. FREX words such as "Pollution" and "Legal" zero in on specific strategies and impacts

**Table 2** Topic labels, top words, FREX words

| Topic labels | Highest probability words | FREX words |
|---|---|---|
| The Role of Innovation and Entrepreneurship in Firm Performance | Innovation, entrepreneurship, factor, firm, effect, performance, role, use, significance, technology, enterprise, also, strategy, impact, relationship | High-tech, solid, imitation, purchase, innovation, Guangdong, embedded, Nigeria, consumer, firm |
| Sustainability in Business Models and Social Entrepreneurship | Sustainability, entrepreneurship, business, model, social, entrepreneur, development, value, practice, opportunity, enterprise, process, find, case, success | Risk, business, multiple, bioeconomy, success, integrate, bottom, sector, ecological, creation, hybrid, logic, john, value, model |
| Developing Innovation Ecosystems in Entrepreneurship | Innovation, entrepreneurship, ecosystem, development, economy, sustainability, dynamic, capability, region, policy, economy, emergence, model, framework | Ecosystem, dynamic, region, festival, knowledge-intensive, capability, economy, emergence, learn, stakeholder |
| Sustainable Development Ventures and the Environment in Entrepreneurship | Sustainability, entrepreneurship, development, venture, environment, social, research, field, author, entrepreneur, article, new, study, framework | Bibliometric, review, systematic, legitimacy, venture, field, research, enable, database, path, big, journal, effectuation, map |
| Economic Development Through Sustainable Entrepreneurship | Sustainability, entrepreneurship, development, entrepreneur, economy, university, crowdfunding, goal, global, business, entrepreneurship, support, policy, SDGs, challenge | Crowdfunding, SDGs, Oman, European, university, farm, apparel, goal, global, union, project, unit, climate, eco-innovation |
| Environmental Quality Management and Development in Entrepreneurship | Environment, entrepreneurship, development, quality, management, sustainability, social, model, product, industry, impact, response, market, economy, result | Quality, cake, Russian, Kuznets, pollution, cup, curve, tax, panel, environment, legal, estimate, construction, run |
| Sustainable Entrepreneurial Intentions and Education | Sustainability, entrepreneurship, entrepreneurial, intent, education, student, attitude, identity, value, university, perceived, development, role, entrepreneur, data | Intent, attitude, student, identity, education, perceived, person, students', college, behavior, training, university, female, undergraduate, desire |
| Green Entrepreneurship: Development and Environmental Impact | Green, entrepreneur, development, environment, entrepreneurship, business, sustainability, product, social, rural, approach, market, challenge, management, local | E-commerce, green, rural, immigrant, Brexit, language, social-benefit, renewable, GAC, geo, system-change, ethic, transition, local |

**Table 2** (continued)

| Topic labels | Highest probability words | FREX words |
|---|---|---|
| Digital Transformation in Innovation and Entrepreneurship | Digital, innovation, entrepreneurship, entrepreneurial, transformation, institutional, business, model, technology, sustainability, company, platform, system, use, entrepreneur | Digital, platform, transformation, effectuation, company, strategy, institutional, Class, DSE, live, lab, connect, DIO, technology |
| The Performance of SMEs in a Sustainable and Environmental Entrepreneurship Context | Sustainability, entrepreneurship, performance, environment, SMEs, orientation, effect, positive, social, enterprise, corporate, result, factor, impact, mediation | SMEs, orientation, corporate, performance, positive, CSR, mediation, SME, small, enterprise, medium, effect, organization, financial |

Source: Authors' own results


*Topic 1*


*Topic 2*


*Topic 3*


*Topic 4*


*Topic 5*


*Topic 6*


*Topic 7*


*Topic 8*


*Topic 9*


*Topic 10*

**Fig. 5** Word clouds of 10 topics. Source: Authors' own results

of entrepreneurial endeavors on environmental quality, underscoring management approaches and regulatory frameworks. Topic 7, "Sustainable Entrepreneurial Intentions and Education," marries the realms of sustainability, entrepreneurship, and educational theory, focusing on forming sustainable entrepreneurial mindsets. Through "Intent," "Education," and "Identity" as key FREX terms, this discussion illuminates the psychological and pedagogical dimensions of cultivating a sustainability-oriented entrepreneurial spirit, particularly within academic environments and among the youth. Topic 8, "Green Entrepreneurship: Development and Environmental Impact," articulates the fusion of entrepreneurship with environmental

goals, utilizing "Green," "Development," and "Environmental" as central terms. The FREX lexicon, including "Rural" and "Renewable," showcases the scope of green entrepreneurship, from promoting eco-friendly business practices to fostering social and rural development, highlighting the sector's versatility and impact. Topic 9, "Digital Transformation in Innovation and Entrepreneurship," examines the confluence of digital technologies with innovative and entrepreneurial practices. Central terms such as "Digital," "Innovation," and "Transformation" emphasize the transformative power of digital tools in reshaping business models and strategies. FREX words like "Platform" and "Company" highlight the critical role of digital platforms and strategic adaptability in modern entrepreneurial ecosystems. Topic 10, "The Performance of SMEs in a Sustainable and Environmental Entrepreneurship Context," looks at how sustainability and environmental considerations influence small and medium-sized enterprises operational and strategic performance. The inclusion of "SMEs," "Corporate," and "CSR" among FREX terms underscores the significance of integrating business operations with sustainability principles, focusing on the resultant organizational performance and social impact, thus providing a comprehensive view of sustainable entrepreneurship's multifaceted nature.

Figure 6 details the proportional distribution of extracted topics from a corpus likely concerning sustainable entrepreneurship, as determined by topic modeling, a machine-learning technique used to identify themes within large textual datasets. It is evident that the most prominent topic, occupying a 15% proportion, is "The Role of Innovation and Entrepreneurship in Firm Performance," signifying a significant scholarly focus on how entrepreneurial and innovative activities contribute to business success metrics. This is followed by "Sustainability in Business Models and Social Entrepreneurship," at 14%, indicating a substantial emphasis on integrating sustainable practices within entrepreneurial frameworks and their social implications. Following topics, such as "Developing Innovation Ecosystems in Entrepreneurship" and "Sustainable Development Ventures and the Environment in Entrepreneurship," command slightly lesser proportions, denoting their relative prevalence and possibly reflecting a focus on the systemic and ecological considerations within

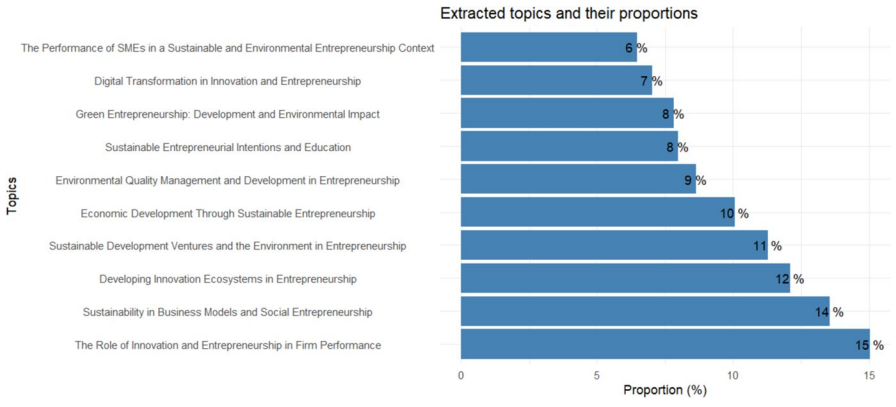


**Fig. 6** Extracted topics and their proportions. Source: Authors' own results

the field. Notably, the "Performance of SMEs in a Sustainable and Environmental Entrepreneurship Context" constitutes the small number proportion at 6%, suggesting it may be an emerging area of research or a niche within the broader context of sustainable entrepreneurship. The graph provides a quantitative overview of the research landscape, revealing the weight of specific topics in the academic dialogue and the distributional hierarchy, which may inform future research directions, funding allocations, and academic discourse.

Figure 7 portrays a scatter plot assessing topic modeling results, with each point representing one of the ten topics derived from a corpus, presumably on sustainable entrepreneurship. The horizontal axis measures semantic coherence, likely indicating how semantically consistent the words within each topic are, which can be interpreted as the intelligibility of a topic to human readers based on the co-occurrence of words within the documents. The vertical axis quantifies exclusivity, which reflects the extent to which the most representative words of a topic are exclusive to that topic and do not frequently occur across other topics, thus serving as distinctive indicators. Topics 2, "Sustainability in Business Models and Social Entrepreneurship," and 7, "Sustainable Entrepreneurial Intentions and Education," exhibit higher exclusivity, suggesting that their defining words are unique to the discussions within these themes. Topics 1, "The Role of Innovation and Entrepreneurship in Firm Performance" and 3 "Developing Innovation Ecosystems in Entrepreneurship" display moderate exclusivity and coherence, indicating a balance between topic uniqueness and internal consistency.

Meanwhile, Topic 9, "Digital Transformation in Innovation and Entrepreneurship," appears to achieve high semantic coherence while retaining less exclusivity, implying that its vocabulary is well understood but common across other topics. Conversely, Topic 6, "Environmental Quality Management and Development in Entrepreneurship," shows lower coherence and exclusivity, which may indicate

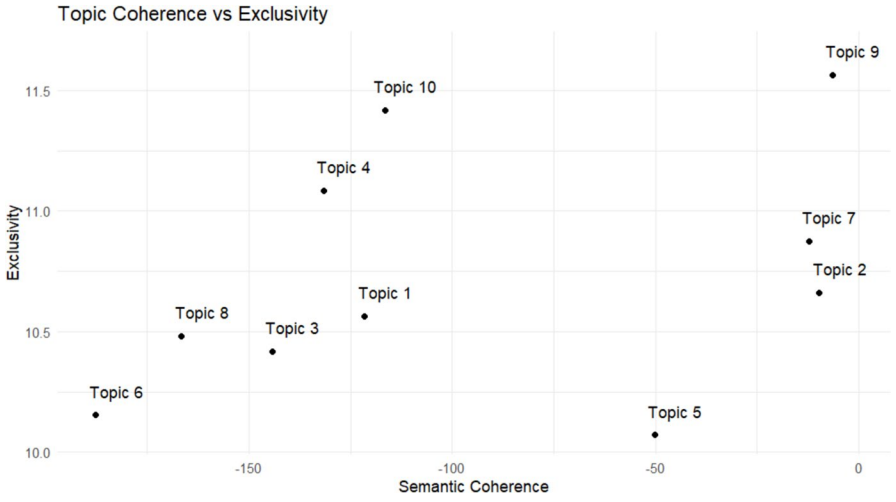


**Fig. 7** Semantic coherence and exclusivity map. Source: Authors' own results

a more interdisciplinary nature or less clarity in its thematic composition. The plot effectively visualizes the trade-off between a topic's distinctiveness and its interpretability, providing insights into the structure of topics that can inform further qualitative analysis and the refinement of topic models for enhanced clarity and differentiation.

Figure 8 presents a network visualization of interrelated topics, mapping the connections and proximity between different areas of discourse within sustainable entrepreneurship. Each node, labeled as Topic 1 through Topic 10, represents a distinct thematic cluster derived from text data analysis, with the connecting lines possibly indicating thematic overlap or relatedness as perceived through co-occurrence or co-citation within the corpus. Topic 1, "The Role of Innovation and Entrepreneurship in Firm Performance" appears central but somewhat isolated, suggesting a foundational yet distinct area within the network. In contrast, Topic 7 "Sustainable Entrepreneurial Intentions and Education" seems to act as a nexus, indicating its thematic relevance to adjacent topics such as Topic 4 "Sustainable Development Ventures and the Environment in Entrepreneurship" and Topic 8 "Green Entrepreneurship: Development and Environmental Impact." The peripheral placement of Topic 9, "Digital Transformation in Innovation and Entrepreneurship," and Topic 2 "Sustainability in Business Models and Social Entrepreneurship" may denote specialized or emerging fields with specific literature. The spatial arrangement of the nodes provides insights into the structure of the scholarly conversation, highlighting both central and specialized themes within the field, which may reflect the current state of research and potential areas for further investigation in the nexus of sustainability, entrepreneurship, and their multifaceted impacts on society and the environment.

Figure 9 appears to be a correlation matrix visualizing the relationships between different topics identified through topic modeling within sustainable entrepreneurship. Each square in the matrix corresponds to the pairwise correlation coefficient

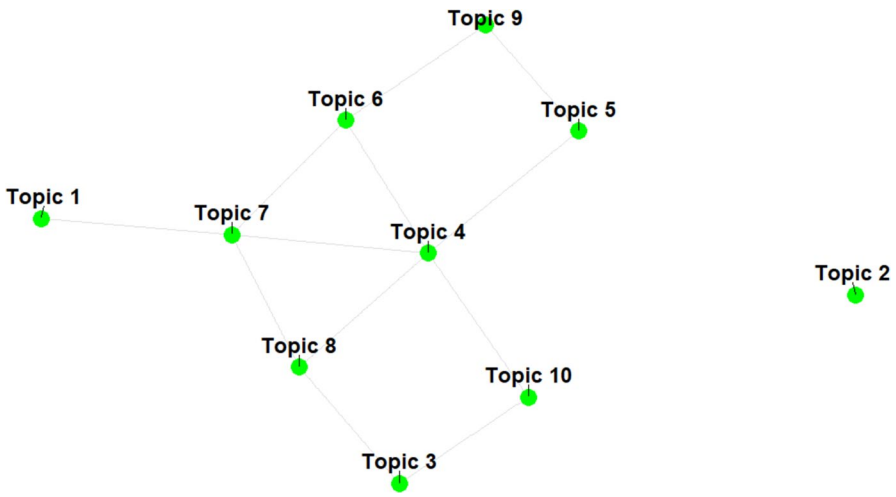


**Fig. 8** Network of topic correlations. Source: Authors' own results

between two topics, quantifying the degree to which they are linearly related within the analyzed texts. The diagonal, shaded the darkest, represents the perfect correlation of each topic with itself (correlation coefficient of 1). The varying shades of orange in off-diagonal squares depict the strength and direction of correlation between different topics: darker shades correspond to stronger relationships, and lighter shades to weaker ones. Negative values indicate inverse relationships, where an increase in one topic's prevalence corresponds to a decrease in another. For example, the correlation between Topic 1 "The Role of Innovation and Entrepreneurship in Firm Performance" and Topic 9 "Digital Transformation in Innovation and Entrepreneurship," may be relatively strong but negative, suggesting that discussions on digital transformation are less likely to coincide with discussions on firm performance through innovation and entrepreneurship within the corpus. This matrix provides a comprehensive overview of the inter-topic dynamics, offering a clear understanding of how various themes within sustainable entrepreneurship relate to one another, which is crucial for discerning the field's multidisciplinary nature and guiding subsequent research inquiries.

The composite Fig. 10 displays a collection of temporal trend analyses for various topics associated with sustainable entrepreneurship, extending from 2014 to 2024.

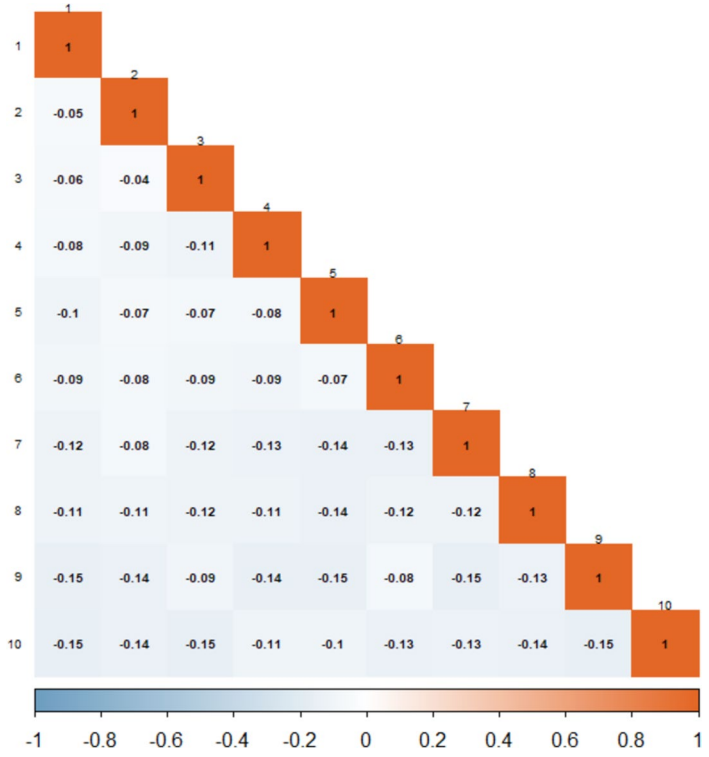


**Fig. 9** Correlation matrix of topics. Source: Authors' own results

Each line graph encapsulates a distinct subject area within the sustainable entrepreneurship field, with the central solid line representing the median prevalence trajectory, flanked by dashed lines that define the 95% confidence interval, offering a statistical boundary within which the true topic prevalence is expected to reside with high probability. A careful examination of these trend lines allows for discerning distinct patterns. For instance, the upward trends in topics such as "Sustainable Entrepreneurial Intentions and Education" and "Digital Transformation in Innovation and Entrepreneurship" suggest a burgeoning interest and increasing scholarly attention. The rise in prevalence could be attributable to the growing recognition of education's role in shaping sustainable entrepreneurial mindsets and the pervasive impact of digital technology in redefining business practices, innovation, and economic paradigms.

In contrast, other topics exhibit relatively stable or smooth trends, indicating a consistent level of academic engagement without significant fluctuations. This steadiness might reflect an established research community and a continuous, albeit moderate, contribution of scholarly work that neither wanes nor intensifies dramatically over time. Such stability is valuable, signifying enduring relevance within the academic discourse and suggesting these areas as foundational pillars of sustainable entrepreneurship literature. Conversely, specific topics demonstrate declining trends, as seen in "The Role of Innovation and Entrepreneurship in Firm Performance," which may hint at a shift in academic focus, possibly due to saturation in the topic or a pivot towards more novel or pressing issues within the sustainability paradigm. Declines could also suggest that the initial impetus that drove the prominence of these topics has diminished, either because key questions have been sufficiently addressed or because other topics have emerged as more critical or urgent in the face of new societal challenges and scientific advancements. These observed trends offer strategic insights for researchers and policymakers. Ascending trends may indicate fertile ground for future research funding, policy initiatives, and academic program development. In contrast, the declining trajectories could prompt a re-evaluation of research agendas or invite inquiry into why these topics are receiving less attention—is it due to a lack of innovation within the topic, shifts in societal priorities, or perhaps a transition towards more integrated and interdisciplinary approaches that dilute the focus on specific, isolated topics? Thus, the figure maps the historical landscape of sustainable entrepreneurship research and serves as a compass for future scholarly navigation, revealing the dynamic interplay between academic interest, societal needs, and the evolution of sustainability as a core principle in entrepreneurial thought and practice.

The heat map displayed in Fig. 11 functions as a sophisticated topic modeling tool, delineating the relative prominence of sustainable entrepreneurship-related topics across a range of scholarly journals, each row designated to a particular journal and each column to one of ten specified topics. The gradation of colors, from light to dark, encapsulates the extent to which these topics are represented within the journals' articles, offering a nuanced spectrum of academic focus. A discernible pattern emerges, where journals such as "Small Business Economics" and "Journal of Business Venturing" exhibit a stronger emphasis on "The Role of Innovation and Entrepreneurship in Firm Performance," a topic pivotal to understanding

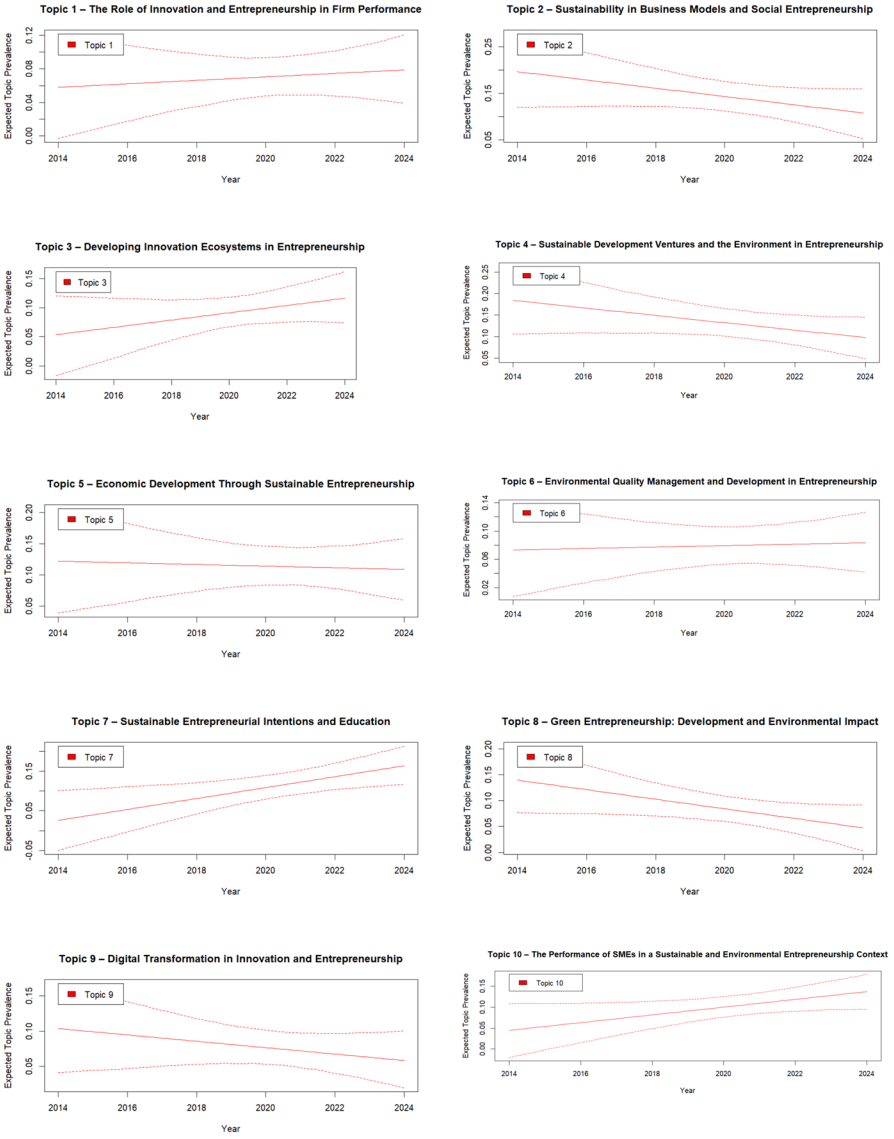


**Fig. 10** Expected topic prevalence over time with 95% confidence intervals. Source: Authors' own results

the mechanics of business success within the sustainability paradigm. Similarly, the "Journal of Cleaner Production" and "Sustainability (Switzerland)" are central to disseminating research on "Sustainable Development Ventures and the Environment in Entrepreneurship," underscoring their influential role in environmental management discussions. In examining the heat map, one can observe a notable concentration in specific journals on "Digital Transformation in Innovation and Entrepreneurship," with "Research Policy" and "Journal of the International Council for Small

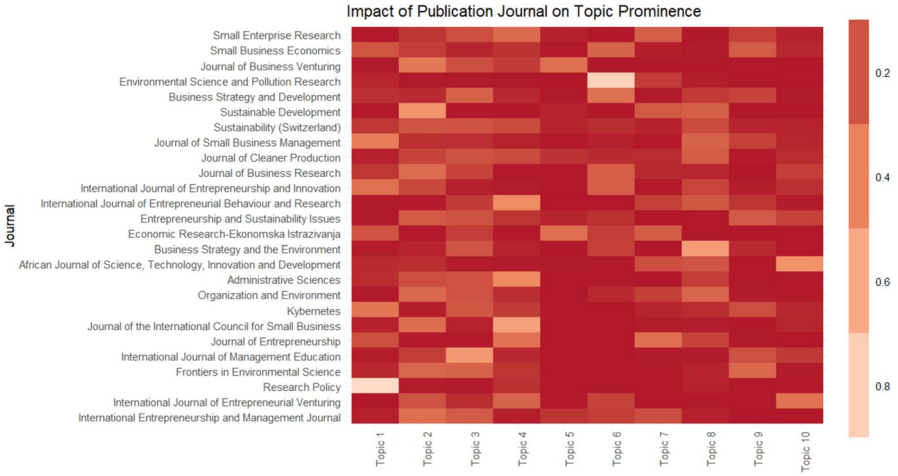


**Fig. 11** Impact of publication journal on topic prominence. Source: Authors' own results

Business" showcasing a higher intensity of this topic, indicative of their impact on propelling digital-centric discourse within the entrepreneurial landscape. Contrastingly, areas such as "Economic Development Through Sustainable Entrepreneurship" and "Green Entrepreneurship: Development and Environmental Impact" present a more distributed emphasis across journals, reflecting a broader engagement with these subjects within the academic community. The heat map serves as a visual guide for researchers seeking appropriate publication venues and as an implicit critique of the current scholarly ecosystem, spotlighting the intellectual territories of various journals. It accentuates the pivotal role of certain publications in shaping the discourse; for example, "Sustainable Development" and "Business Strategy and the Environment" emerge as key contributors to the conversation on "Sustainability in Business Models and Social Entrepreneurship," a topic of immense relevance in a world grappling with socio-ecological challenges. By highlighting the relationship between journals and topic prominence, the heat map also implicitly suggests the influence of certain journals as thought leaders in specific domains within the sustainability discourse. This comprehensive visualization not only assists in strategically disseminating research findings but also provides an evaluative metric for the influence of academic literature on the development and maturation of topics in sustainable entrepreneurship, guiding scholars through the intellectual landscape of sustainability scholarship.

## Discussion on result, five major trends, and implications

### Innovation and sustainable entrepreneurship

The incorporation of innovation into the entrepreneurial sphere, particularly within the context of sustainable entrepreneurship, presents a dynamic and

multifaceted domain of inquiry that is important for understanding the mechanisms through which firms achieve enhanced performance (Baiocco and Paniccia 2023; Bakry et al. 2024a, b). Studies such as those exploring the proposed metrics for assessing dynamic capabilities in firms (Guerrero and Siegel 2024) and the role of innovation ecosystems (Bakry et al. 2024a) highlight the importance of a strategic plan for sustainable growth and competitive advantage (Alsafadi and Aljuhmani 2023). Such as, the available investigations highlight how innovation, when effectively integrated into the entrepreneurial fabric (Ouano and Mazzarella 2021), can drive significant improvements in firm performance by fostering agility (Diale et al. 2021), responsiveness, and a sustainable competitive edge (Abbas and Bulut 2024). This relationship is further explained through the lens of sustainable entrepreneurship, where the imperative for environmental and social responsibility demands innovative aspects of business that balance economic objectives with sustainability goals (Pastran et al. 2021; Xu et al. 2022).

In the realm of sustainable entrepreneurship, the exploration of specific sectors such as agriculture(Mujeyi et al. 2015) and healthcare (Wallin 2017), alongside broader considerations of sustainable development within mass entrepreneurship networks (Wang et al. 2023), provides compelling evidence of the transformative impact of innovation (Li and Long 2023). These studies reveal that entrepreneurial performance in today's global economy (Guerrero and Urbano 2017; Khalid 2020; Khalid et al. 2020) is increasingly contingent upon the ability to promote innovation in addressing complex sustainability challenges (Thompson and Scott 2010; Hofmann et al. 2022). For instance, deploying entrepreneurial innovations has not only aimed at achieving sustainability but also enhances the resilience and performance of enterprises within this sector (Wallin 2017; Ignatov 2019; Mukesh 2022). The cumulative insights from these investigations (Mujeyi et al. 2015; Wallin 2017; Wang et al. 2023) present a comprehensive picture of the integral role of innovation in driving both the performance and sustainability agendas of entrepreneurial firms.

Moreover, the discussions around the higher intelligence of the "creative minority" (Burhan et al. 2017) and the contextualization of entrepreneurial innovation within sustainable ventures (Garud et al. 2014) offer clear perspectives on the strategies and frameworks that underpin the successful integration of innovation into entrepreneurial practices. The literature trends (Sr Nos 347, 354) emphasize the significance of creative and strategic thinking in cultivating a culture of innovation that permeates all levels of the enterprise (Guerrero and Martínez-Chávez 2020; Khalid et al. 2020; Tsolakidis et al. 2020; Qin 2024). By adopting a holistic approach to innovation, characterized by a deep understanding of the interplay between environmental, social, and economic dimensions, firms can enhance their performance and contribute meaningfully to the global sustainability agenda (Konys 2019; Huarng and Yu 2022). Collectively, the research summed up by these citations (Wang et al. 2023; Bakry et al. 2024a; Guerrero and Siegel 2024) provides a robust framework for understanding the critical relationship between innovation and entrepreneurial performance, underscoring the essential role of innovative thinking and practices in the pursuit of sustainable entrepreneurship.

### Harmonization of sustainability in business models and entrepreneurship

The harmonization of sustainability in business models and entrepreneurship represents a profound shift in the strategic orientation of modern enterprises, transitioning from conventional profit-centric models to those that integrate economic, environmental, and social considerations (Hahn et al. 2018; Matzembacher et al. 2020; Gregori et al. 2024). This transition is not merely a response to regulatory pressures (Fischer et al. 2018)or market demands (Cipollone and Giordani 2019; Han and Niu 2022) but reflects a broader recognition of the intrinsic value that sustainability adds to long-term business success and societal well-being (Ezennia and Mutambara 2020; Kanayo et al. 2021). Sustainable entrepreneurship has emerged as a dynamic field where innovation, strategic foresight, and a commitment to sustainability principles converge to redefine the business excellence (Han and Niu 2022; Pierscieniak et al. 2023). In addition to addressing the demanding issues of social injustice and environmental degradation, entrepreneurs create new avenues for innovation, economic advantage, and market leadership by incorporating sustainability into their fundamental business models (Johnsen 2023; Bakry et al. 2024a; Gregori et al. 2024).

These aspects encompass a wide array of practices, from the development of technologies (Gregori and Holzmann 2020) and the adoption of circular economy principles (Gruba et al. 2022) to the implementation of socially responsible policies and the pursuit of equitable growth (Khokhawala and Iyer 2022). These model concepts demonstrate the multifaceted nature of sustainable entrepreneurship, where environmental stewardship, social equity (Proença and Soukiazis 2023), and economic viability are seen as interconnected pillars rather than conflicting objectives (Gu and Wang 2022; Chochia et al. 2023; Joana Carolina et al. 2024). By integrating sustainability into business models, entrepreneurs can take advantage of the interrelationships across these pillars to generate value beyond the company and stakeholders, communities, and ecosystems (Bischoff and Volkmann 2018; Audretsch et al. 2023). Furthermore, the trend towards the variation of different models offers new pathways for enhancing efficiency, reducing environmental impact, and facilitating inclusive economic participation (Avelar et al. 2024).

Moreover, successfully consistent sustainability in business models and entrepreneurship demands a supportive ecosystem that fosters collaboration, modernization, and knowledge sharing (Audretsch et al. 2023; Huang et al. 2023). This ecosystem includes a diverse network of actors, including government officials, investors, consumers, and academia, each playing a crucial role in creating an enabling environment for sustainable ventures (Iqbal et al. 2020; Tenner and Hörisch 2021). Policy frameworks, financial instruments, and educational programs are essential to this ecosystem, providing entrepreneurs' resources, incentives, and capabilities to succeed (Joensuu-Salo et al. 2022; Sadiq et al. 2022). The joint efforts of this ecosystem will be crucial in accelerating the worldwide shift towards more resilient and sustainable business, and entrepreneurs negotiate the challenges of incorporating sustainability into their operations (Havierniková and Kordoš 2019; Nave and Franco 2019).

### Environmental management within green entrepreneurship

Environmental management within green entrepreneurship is a growing field where business innovation intersects with ecological direction, underpinning a transformative approach to entrepreneurship and sustainability (Johnsen 2023; Tran 2024). This intersection fosters a unique space for entrepreneurs to leverage environmental challenges as opportunities for novelty, creating ventures that contribute positively to the planet's health while ensuring economic sustainability (Shahid et al. 2023). The spirit of green entrepreneurship rests in its capacity to coordinate environmental management practices with entrepreneurial dedication, pushing companies that reduce ecological footprints and tap into expanding markets for sustainable products and services. (Johnsen 2023; Tran 2024). This dual focus reflects a deeper understanding of the intrinsic link between environmental health and business success, pushing the boundaries of traditional entrepreneurship to include sustainability as a core component of business strategy and operational ethos (Nikolaou et al. 2018).

The characteristics of environmental management within green entrepreneurship are as diverse as the ecosystems; they aim to protect the development and implementation of green technologies to the adoption of circular economy principles (Madzikanda et al. 2023; Siqueira et al. 2023). These practices are not merely about compliance or mitigating adverse impacts but are driven by a vision of creating sustainable value that extends beyond the enterprise to society (Afum et al. 2023; Tran 2024). By integrating environmental considerations into every aspect of the business process, green entrepreneurs challenge the status quo (Pricopoaia et al. 2024), advocating for a shift towards business practices that prioritize long-term ecological sustainability over short-term gains (Le Loarne Lemaire et al. 2022; Rajkamal et al. 2022). This shift is facilitated by a growing body of knowledge and innovation in sustainable practices, enabling entrepreneurs to explore new profitable and sustainable business ways (Bergset and Fichter 2015; Nikolaou et al. 2018).

Likewise, the successful implementation requires a supportive ecosystem that includes favorable policies (Sáez-Martínez et al. 2014; Guerrero and Urbano 2019), access to green finance (Sadiq et al. 2022), and a culture (Swanson and DeVereaux 2017) that values sustainability. ollaboration among various stakeholders, investors, consumers, and academia is crucial in creating an environment where green ventures can thrive (York et al. 2016; Bischoff and Volkmann 2018; Baranova 2024). As this field continues to evolve, exchanging ideas and best practices among green entrepreneurs fosters a dynamic community committed to advancing sustainability (Nave and Franco 2019). The trends show that the journey of green entrepreneurship is a deep commitment to environmental stewardship, embodying a hopeful vision for the future where green venture and ecological health are linked, paving the way for a more sustainable world.

### Role of education in fostering sustainable entrepreneurial intentions

From an extensive review of the literature on sustainable entrepreneurship, it becomes increasingly apparent that education plays a central role in fostering

sustainable entrepreneurial intentions (Gupta et al. 2023a; Hogenstijn and Cuypers 2023). Integrating sustainability concepts within educational frameworks equips future entrepreneurs with the necessary knowledge and skills for societal and environmental well-being (Joensuu-Salo et al. 2022; Klapper and Fayolle 2023). This education goes beyond traditional business insight (Zhang et al. 2024), emphasizing green absorptive capacity, ecological responsiveness, and the ethical dimensions of entrepreneurship (Lans et al. 2014; Subekti et al. 2019; Zahrani 2022). Studies, such as those examining the impact of green industrial revolutions and sustainable practices across different sectors, underscore the transformative potential of education in aligning entrepreneurial targets with sustainability goals (Chen et al. 2023; Madzikanda et al. 2023).

The dynamic interplay between education and sustainable entrepreneurship is further illuminated through comparative analyses of early-stage ventures across diverse cultural contexts (Mohamad and Nasir 2019; Tehseen and Haider 2021; Khokhawala and Iyer 2022). These studies reveal that educational initiatives tailored to address sustainability challenges can significantly influence entrepreneurial intentions. For instance, learning environments that encourage critical thinking, innovation, and a deep understanding of sustainability issues can catalyze the development of sustainable entrepreneurial intentions (Vuorio et al. 2018; Joensuu-Salo et al. 2022). By fostering an educational milieu that nurtures these competencies, individuals are better prepared to go on board entrepreneurial ventures that seek financial success and contribute positively to societal and environmental outcomes (Zahrani 2022; Hogenstijn and Cuypers 2023).

The emphasis on education in fostering sustainable entrepreneurial intentions is evident in the growing body of literature advocating for the integration of sustainability into the curricula of business schools and other educational institutions (Baber 2023; Klapper and Fayolle 2023). This shift is crucial for preparing a new generation of entrepreneurs who practiced identifying and developing business opportunities and are committed to addressing the environmental challenges of our time (Diepolder et al. 2024). As such, education's role in shaping sustainable entrepreneurship's future cannot be overstated, highlighting its importance in cultivating a more sustainable and inclusive global economy (Thelken and de Jong 2020; Joensuu-Salo et al. 2022).

#### Enhancement of SMEs in sustainable entrepreneurship context

In the contemporary business landscape, the development of SMEs through sustainable entrepreneurship has emerged as a critical area of academic and practical inquiry (Soto-Acosta et al. 2016; Pierscieniak et al. 2023; Avelar et al. 2024). This paradigm examines SMEs' performance metrics and delves into their novel capacities within sustainability and environmental management (Avelar et al. 2024). The corpus of research in the provided dataset offers a clear and better understanding of how SMEs navigate the complexities of integrating sustainable practices into their operational, strategic, and innovative ventures (Ferreira and Ferreira 2023). It suggests that merging sustainability principles with business operations is essential for

SMEs aiming to achieve long-term viability, resilience, and competitive differentiation in an increasingly eco-conscious market landscape (Qader et al. 2022; Pierscieniak et al. 2023).

Furthermore, the discourse on sustainable entrepreneurship within SMEs underscores the significance of innovative ecosystems conducive to sustainable development (Avelar et al. 2024). These ecosystems, characterized by collaborative networks, technological advancements, and policy frameworks supportive of green entrepreneurship, facilitate SMEs' transition towards sustainability-oriented business models (Peng and Walid 2022). The scholarly works highlighted the necessity for SMEs to connect digital transformation and green innovation as mechanisms for reducing environmental footprints while unlocking new opportunities for growth and value creation (Chatterjee et al. 2022; Nuseir and Aljumah 2022). In essence, the ability of SMEs to insert sustainability into their innovation processes indicates their role in pursuing a more sustainable and equitable global economy (Soto-Acosta et al. 2016).

Incorporating sustainability into SMEs' operational behaviors is complexly linked to the broader theme of sustainable entrepreneurial training (Kummitha and Kummitha 2021; Zahrani 2022). This factor stresses the importance of developing a mindset among SME leaders and entrepreneurs that aligns with the principles of environmental sustainability, social equity (Arista-Cancino and Colina-Ysea 2024), and economic inclusivity (Raudeliuniene et al. 2014; Moya-Clemente et al. 2020). The analysis reveals that these training initiatives and knowledge spreading affecting sustainable entrepreneurship are critical in empowering SME stakeholders to make informed decisions that reflect a commitment to sustainability (Soto-Acosta et al. 2016; Bajdor et al. 2021). By fostering an organizational culture that prioritizes learning and adaptation in sustainability, SMEs can spearhead innovative solutions to contemporary environmental challenges, contributing significantly to the global agenda for sustainable development (Eller et al. 2020; Hummels and Argyrou 2021). Through this lens, sustainable entrepreneurship emerges as a business strategy and transformative force that enhances SMEs' capacity to contribute to a more sustainable future (Esteves et al. 2021; Johnson and Hörisch 2022; Mohapatra et al. 2024).

### Policy and practical implications and specific suggestions

The findings of this study carry significant implications for various stakeholders. For businesses, the data highlights the imperative of embedding sustainability at the core of their operations. Entrepreneurs are encouraged to view sustainability not merely as a compliance measure or branding strategy but as a strategic principle essential for long-term value creation and competitive differentiation (Burhan et al. 2017; Middermann et al. 2020). Entrepreneurship platforms should use these insights to develop tools, resources, and training that support startups and SMEs in adopting sustainable practices from their inception.

Government policymakers can draw on this research to craft policies aligning with sustainable entrepreneurship's evolving dynamics (Chochia et al. 2023; Hällerstrand et al. 2023). Recommendations include creating incentives for green

technology adoption, supporting environmental quality management initiatives, and fostering investment in sustainable ventures. Furthermore, the study highlights the transformative potential of digital technologies in driving sustainability across industries, suggesting an urgent need for policies that encourage the integration of digital tools to enhance efficiency and foster innovation in sustainable practices (Gupta et al. 2023b; Joana Carolina et al. 2024).

This research provides valuable insights for entrepreneurs, policymakers, educators, and researchers. Entrepreneurs can use these findings to align their strategies with emerging trends, such as digital transformation and green entrepreneurship, which are increasingly critical for market competitiveness and sustainability. Educational institutions can incorporate these themes into their curricula, nurturing a new generation of entrepreneurs equipped to address complex sustainability challenges. Policymakers can use the identified trends to refine existing frameworks and develop targeted incentives promoting sustainable entrepreneurship.

Based on the findings, this study offers the following specific recommendations:

- Entrepreneurs should prioritize innovation and sustainability as core principles, leveraging digital tools to enhance operational efficiency and drive green business practices.
- Educational institutions should integrate sustainability-focused modules into entrepreneurial training programs to cultivate sustainable entrepreneurial intentions among students.
- Policymakers should introduce incentives and support mechanisms that encourage businesses to adopt sustainable practices, such as tax benefits for green initiatives and funding for research in sustainability-driven technologies.

## Conclusion and future research

This study systematically applied STM to analyze and synthesize the evolving thematic discourse within the sustainable entrepreneurship literature. Drawing from an extensive dataset of 363 peer-reviewed articles indexed in Scopus over 10 years, the research employed advanced text-mining techniques that integrated metadata, enabling a comprehensive examination of topic prevalence and interrelationships influenced by covariates such as publication year and source impact. This methodology facilitated quantitative and qualitative insights, uncovering ten distinct thematic areas within sustainable entrepreneurship, including the role of innovation, sustainability in business models, and the integration of environmental objectives in entrepreneurial ventures. By dynamically incorporating external factors, STM enhanced traditional methods such as LDA, offering a deeper understanding of thematic evolution and shifts over time.

Beyond identifying topics, this study analyzed their coherence and correlation, employing visual tools such as network diagrams and heat maps to elucidate the complex patterns of thematic development. The findings demonstrated how such issues as digital transformation and green entrepreneurship have become increasingly interconnected with core sustainable entrepreneurship themes, mirroring

broader socio-economic shifts towards sustainability. The source titles and publication years analysis revealed temporal trends, emphasizing a growing academic focus on embedding sustainability into core business strategies and educational paradigms. Thus, the application of STM highlighted the present state of scholarly discourse and projected potential trajectories for future research, emphasizing the vital role of innovative methodologies in advancing bibliometric studies within this domain.

Moreover, the following future research directions are recommended to enrich the field further:

- Deepen the exploration of digital transformation impacts within sustainable entrepreneurship to assess how emerging technologies can further contribute to sustainability goals across different industries.
- Examine the influence of international and local regulatory changes on the strategic orientation of sustainable businesses, focusing on different environmental and social governance frameworks.
- Investigate the role of innovation ecosystems in fostering sustainability-oriented ventures, particularly how collaboration between academic institutions, industries, and governments can be optimized.
- Conduct longitudinal studies to measure the effectiveness of sustainability integration into business models over time and its impact on firm performance and market competitiveness.
- Explore the psychological and pedagogical aspects of sustainable entrepreneurial intentions, focusing on how educational programs can be designed to nurture future green entrepreneurs effectively.
- Analyze the role of green finance and investment in accelerating the growth of sustainable ventures, identifying the financial mechanisms that most effectively support environmental entrepreneurship.
- Scalability of successful sustainable business practices, identifying the factors that enable or inhibit the expansion of small to medium-sized enterprises (SMEs) in different geographic and economic contexts.

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**Data availability** The data used in the manuscript was uploaded to the Mendeley data repository, and the link is 10.17632/mwjwz5x6dp.1.

## Declarations

**Consent for publication** All the authors provided their explicit consent for the publication of this manuscript.

**Competing interests** The authors declare no competing interests.

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