

Is sustainable tourism actually serving the SDGs? Insights from scientometrics and BERTopic analysis of research evolution and future trajectories

Maniraj Bonkuri, N. Akshaya and S. Yamini

Abstract

Purpose – Sustainable tourism is increasingly recognised as a strategic instrument for advancing the United Nations Sustainable Development Goals (SDGs). However, the field lacks a data-driven synthesis that traces the evolution of themes over time and links emerging research trajectories to SDG-aligned governance frameworks. This study maps the intellectual landscape of sustainable tourism research and forecasts its future direction using an integrated scientometric and machine-learning methodology.

Design/methodology/approach – Scientometric analysis was combined with BERTopic modelling applied to 3,223 peer-reviewed articles (2005–2025) from Scopus and Web of Science. The pipeline integrated MiniLM-L6-v2 sentence embeddings, UMAP dimensionality reduction, HDBSCAN clustering, c-TF-IDF topic representation, GPT-4-assisted labelling and manual SDG mapping. Prophet-based time-series forecasting was then used to project research trajectories through 2030.

Findings – Eighteen thematic clusters organised into four super-topics (consumer behaviour core, cultural and place-based convergence, policy and governance and environmental operations) demonstrate how sustainable tourism research engages with 6 key SDGs (8, 11, 12, 13, 15 and 17). Forecasting identifies four trajectory clusters: sharp growth in tourist behaviour and green hotel practices; gradual acceleration in carbon management and smart tourism technologies; decline in traditional sustainability indicators and stable activity in cultural heritage and rural tourism.

Research limitations/implications – The findings offer KPI frameworks for hotel operators, evidence-based governance tools for policymakers and DMOs and a forward-looking research agenda for scholars.

Originality/value – This study is among the first to combine BERTopic with prophet forecasting within an SDG-linked tourism corpus, transforming bibliometric review into a predictive, decision-support instrument.

Keywords Sustainable tourism, BERTopic, SDGs, Scientometric analysis, Topic modelling, Prophet forecasting, SDG alignment, Temporal forecasting, Hospitality sustainability

Paper type Research article

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1. Introduction

The contemporary discourse surrounding sustainable development is increasingly defined by global imperatives such as climate accountability, responsible consumption, and inclusive economic growth, shifts acutely visible in the rapid expansion of post-pandemic tourism research. As environmental degradation, climate change, and social inequality intensify, the tourism sector is being re-evaluated not only as a contributor to these

challenges but also as a potential instrument for addressing them (Becken, 2013; Barakagira and Paapa, 2023). Sustainable tourism represents a significant shift in this narrative, offering a pathway that balances the preservation of cultural heritage, environmental conservation, and economic viability (European Commission, 2020; Strippoli *et al.*, 2024). Within this context, sustainable tourism, particularly heritage tourism, has gained significant global attention as an innovative and responsible travel model (Tritto, 2020; Tahiri *et al.*, 2022).

Over the past decade, the Sustainable Development Goals (SDGs) have been established as a global framework recognising the need for coordinated action to address poverty, inequality, and environmental challenges. The SDGs represent a universal call to action for all countries, regardless of their economic status, to promote prosperity while protecting the planet (UN, 2015). Sustainable tourism is increasingly recognised as a strategic instrument for advancing these goals, particularly within developing countries (Higgins-Desbiolles, 2018). Beyond leisure, tourism has evolved into a dynamic mechanism for inclusive growth, cultural preservation, and ecological protection (Tahiri *et al.*, 2022). Cultural tourism, heritage conservation, and ecotourism actively contribute to environmental sustainability by preserving landscapes, conserving biodiversity, and nurturing a sense of stewardship among tourists and host communities (Arumugam *et al.*, 2023). Regenerative tourism takes this further by actively restoring ecosystems, empowering communities, and fostering harmony with local social-ecological systems (Bellato *et al.*, 2023). These forms of tourism bridge tradition and transformation, enabling marginalised populations to preserve their cultural assets while engaging with global markets.

The 2030 Agenda for Sustainable Development positions tourism as a key driver of inclusive and sustainable growth. It calls for policies that promote sustainable tourism, particularly those that generate employment and support local culture and products, while underscoring the need for tools to monitor the sustainability impacts of tourism. It also aims to increase economic benefits from tourism for Small Island Developing States (SIDS) and Least Developed Countries (LDCs).

Sustainable tourism strategically supports the UN SDGs by aligning economic, social, and environmental goals. Economically, it reduces poverty (SDG 1), promotes decent jobs and inclusive growth (SDG 8) (Judge *et al.*, 2021; Seyfi *et al.*, 2022; Buzinde and Caterina-Knorr, 2023; Luu, 2024) and fosters innovation and infrastructure through green investment (SDG 9). Socially, it improves health and well-being (SDG 3), advances gender equality (SDG 5) (Osman and Brown, 2024) and supports sustainable communities through cultural preservation and urban renewal (SDG 11) (Kuo *et al.*, 2018; Tuan (Tuan Luu), 2018; Hu *et al.*, 2019; Taş Gürsoy, 2020). Environmentally, it enhances water management (SDG 6) (Gatt and Schranz, 2015), encourages responsible consumption (SDG 12), addresses climate change through low-carbon practices (SDG 13), protects marine ecosystems (SDG 14) (Judge *et al.*, 2021), (2020), and promotes biodiversity and land conservation (SDG 15) (Taş Gürsoy, 2020). Table 1 highlights existing scholarly contributions that examine the intersection of sustainable tourism and the SDGs.

Despite growing scholarly interest in sustainable tourism and its alignment with the SDGs, the field lacks a comprehensive, data-driven synthesis that traces the evolution of themes over time and links emerging research trajectories to SDG-aligned frameworks. Most existing reviews rely on manual or keyword-based bibliometric methods that offer limited capacity to uncover latent thematic structures, track temporal dynamics, or forecast future research directions. To address this gap, this study employs advanced scientometric methods, combined with BERTopic modelling, to systematically investigate the sustainable tourism research landscape.

Table 1 Key scholarly contributions linking sustainable tourism to the SDGs outcomes

<i>Authors</i>	<i>Key findings</i>	<i>SDG goals</i>
Antwi <i>et al.</i> (2025)	In sustainable tourism, residents' mindfulness enhances their hospitality and reduces negative stereotypes toward tourists by fostering greater self-transcendence and atonements, especially when they can take the tourists' perspective	SDG 11, SDG 16, SDG 17
Osman and Brown (2024)	Gender and religion significantly influence the travel experiences of female Muslim tourists, highlighting the need for destinations to support gender equity and cultural sensitivity to promote socially sustainable tourism	SDG 5, SDG 10, SDG 11, SDG 16
Luu (2024)	Customer green involvement positively influences tourism employees' green creative behaviour through the dual mediation of green role identity and green creative self-efficacy, with organisational green culture moderating these effects	SDG 8, SDG 12, SDG 13, SDG 17
Buzinde and Caterina-Knorr (2023)	Tourism development policies in Kenya and Rwanda partially align with inclusive development goals, highlighting gaps in participatory processes, ecological justice, and wealth redistribution, calling for tourism to support decolonial, equitable, and locally defined development approaches	SDG 10, SDG 13, SDG 16, SDG 8
Judge <i>et al.</i> (2021)	Lack of transparency and misleading advertising by South Africa's BBWW operators undermine ecological sustainability and create a conflict between tourist expectations and legal compliance	SDG 14, SDG 12, SDG 8, SDG 13
Seyfi <i>et al.</i> (2022)	Sanctions, though intended as a peacebuilding tool, have severely undermined the peacebuilding capacity and the development of the tourism industry in Iran due to their psychological, sectoral, and societal impacts, as well as mobility restrictions	SDG 8, SDG 16, SDG 17
Tritto (2020)	Environmental management practices (EMPs) in heritage tourism accommodations are shaped by hotel type, with boutique and guesthouse hotels adopting blended technological and traditional methods. At the same time, customer preferences can negatively impact EMP adoption	SDG 11, SDG 12, SDG 13, SDG 8
Kang and Nicholls (2021)	A positive correlation exists between travellers' pro-environmental attitudes and their willingness to pay more for green lodging, with income significantly influencing them	SDG 12, SDG 13, SDG 8
Taş Gürsoy (2020)	Horse-drawn carriages reflect complex ethical, socio-cultural, and political dimensions of tourism, requiring inclusive, multispecies sustainability approaches and regulatory frameworks that involve both public and civil stakeholders	SDG 11, SDG 12, SDG 15, SDG 16
Hu <i>et al.</i> (2019)	Effective water demand management (WDM) in tourism, particularly in Singapore's hotel sector, requires evolving and increasingly complex collaboration among diverse stakeholders to support sustainable destination development	SDG 6, SDG 11, SDG 12, SDG 17
Tuan (2020)	Environmentally specific servant leadership enhances tourism employees' green creativity through green role identity and green-related resource- and challenge-seeking behaviours, but not through green task-demand-reducing behaviour	SDG 8, SDG 12, SDG 13
Kuo <i>et al.</i> (2018)	Innovative, stewardship-based differentiation strategies, grounded in personal values, community engagement, and eco-tourism, are critical for sustaining B&B businesses facing oversupply and homogeneity	SDG 8, SDG 11, SDG 12
Tuan (Tuan Luu) (2018)	Corporate social responsibility (CSR) positively influences tourists' and employees' environmental citizenship behaviours, with mutual reinforcement between customer CBE and employee OCBE, and environmentally specific servant leadership enhancing CSR's impact on employee OCBE	SDG 11, SDG 12, SDG 13, SDG 17
Lane and Kastenholz (2015)	Rural tourism has evolved significantly but now faces challenges such as competition, governance gaps, and societal changes; a research-led, holistic, and professionally managed "New Generation Rural Tourism" is needed to ensure sustainability and destination development	SDG 8, SDG 11, SDG 12
Gatt and Schranz (2015)	Non-intrusive, low-cost water-saving hotel retrofits can significantly reduce water consumption, enhancing sustainability in tourism-heavy regions	SDG 6, SDG 12, SDG 13

Source(s): Authors' work

The following research questions (RQs) were developed to guide this inquiry:

- RQ1. How has sustainable tourism research evolved, and what is its significance in relation to the advancement of the Sustainable Development Goals (SDGs)?
- RQ2. What are the key thematic clusters within sustainable tourism research, and how do they align with specific SDG targets and objectives?

RQ3. What emerging trends can be identified through temporal analysis and future forecasting in sustainable tourism research, and how can these insights inform future interventions for attaining sustainable development?

This study delivers several significant contributions to sustainable tourism scholarship. First, it provides a comprehensive performance overview of the existing literature through bibliometric evaluation, employing key indicators such as publication trends, citation patterns, and author collaborations to map the research landscape. Second, it applies BERTopic modelling (Grootendorst, 2022) to segment the literature into interpretable thematic clusters, offering insights into the macro-level structural composition of sustainable tourism research. Third, by mapping these clusters to relevant SDG targets, the study provides a nuanced interpretation of how various research areas contribute to global sustainable development objectives. Fourth, through temporal forecasting and trend analysis using Prophet (Taylor and Letham, 2018), it identifies emerging research priorities and projects their trajectory through 2030. In doing so, the study not only enhances academic discourse by addressing conceptual and methodological fragmentation but also supports the operationalisation of sustainable tourism as a tool for inclusive, resilient, and measurable progress toward the SDGs.

A key methodological contribution of this study is the integration of BERTopic modelling into the analysis of sustainable tourism scholarship. Unlike conventional approaches such as keyword co-occurrence mapping or Latent Dirichlet Allocation (LDA), BERTopic leverages contextual sentence embeddings to capture semantic nuance across large, heterogeneous corpora, rather than relying solely on word frequency. This is particularly valuable in sustainable tourism research, where overlapping terminologies across disciplines can confound keyword-based classification. Moreover, BERTopic's compatibility with temporal analysis enables dynamic tracking of research theme evolution, and its integration with Prophet-based forecasting transforms static literature mapping into a forward-looking, predictive instrument, making it uniquely suited to the SDG-aligned, trajectory-forecasting objectives of this study.

The subsequent sections are organised as follows (See Figure 1). Section 2 details the research methodology, including article selection, pre-processing, the topic modelling framework, and the forecasting approach. Section 3 presents the BERTopic-derived thematic clusters and their alignment with the SDGs. Section 4 explores the semantic landscape of research themes through inter-topic distance mapping and related visualisations. Section 5 conducts predictive analysis using Prophet-based forecasting to project research trajectories through 2030. Section 6 provides a comprehensive discussion of the findings, including key insights, research gaps, and super-topic synthesis. Section 7 outlines implications for performance management, policy, and future research, and Section 8 presents the conclusion.

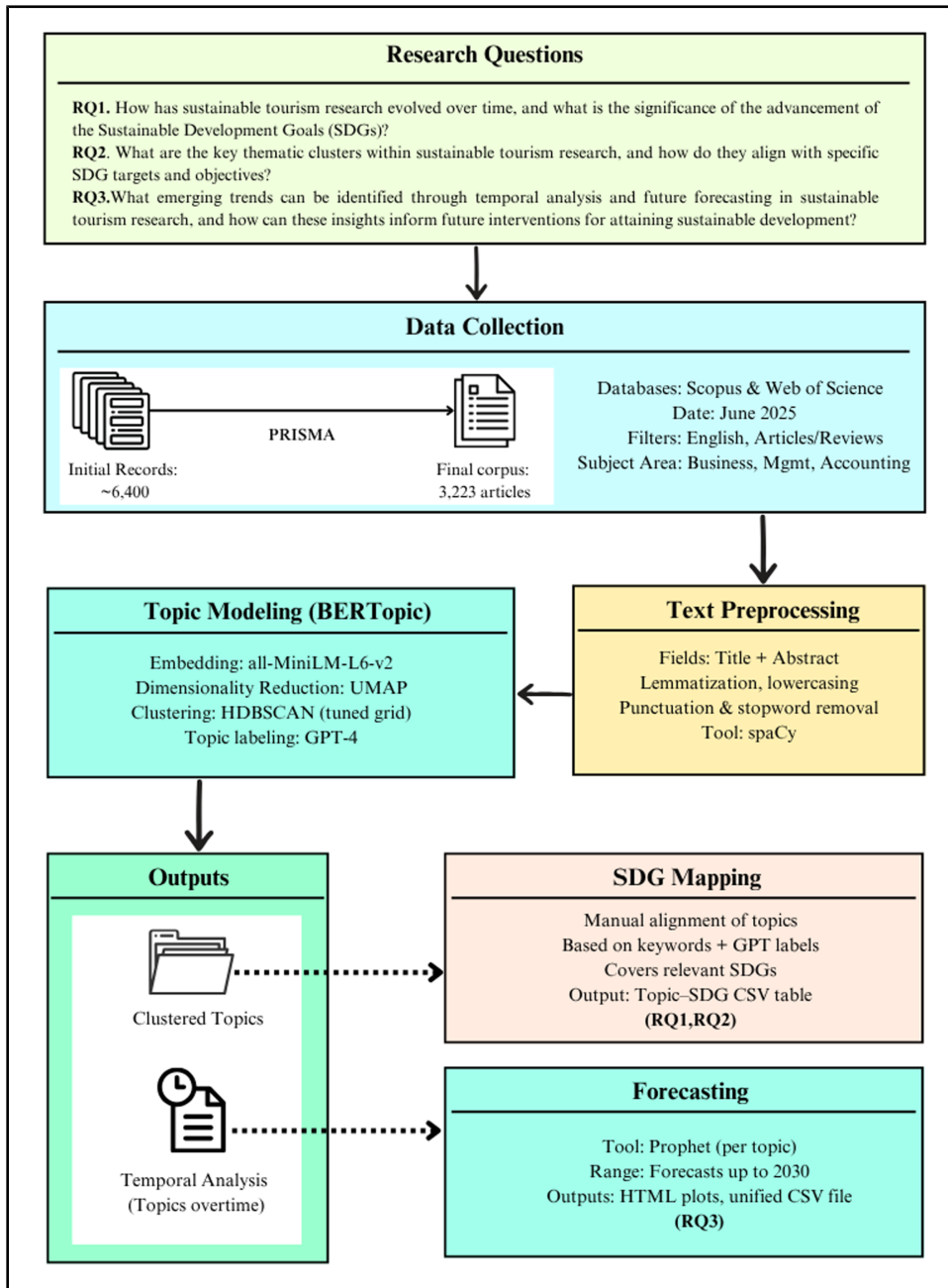
2. Methodology

To systematically explore the intersection of tourism and sustainability, we employed structured queries across two leading bibliographic databases, Scopus and Web of Science (WOS). The search targeted literature on tourism and sustainability, focusing on cultural, ecological, and policy-oriented dimensions. To provide transparency and reproducibility, the article selection process followed PRISMA guidelines (Page et al., 2021).

2.1 Article selection

The search strategy employed a Boolean query combining key terms from tourism and sustainability domains to ensure thematic alignment with the study's objectives. The Boolean query focused on terms related to tourism (e.g. "cultural tourism", "eco-tourism", "travel planning") and sustainability (e.g. "climate resilience", "circular economy", "green innovation"). These terms were restricted to the abstract field for conceptual precision. Table 2 presents the sequential filtering process, reducing 6,400 initial records to 3,223 relevant articles based on

Figure 1 Study design. Source: Authors' work



subject area, document type, language, and final content screening. In addition, the more general keyword “sustainability” was also searched across all fields to ensure broader applicability.

2.2 Pre-processing

After article selection, the obtained records were subjected to a text pre-processing pipeline to prepare the corpus for topic modelling. Titles and abstracts were merged into one column to increase contextual depth and semantic comprehension. (Zhang *et al.*, 2010).

Table 2 Article selection criteria		
Criteria	Accept	Reject
Initial data retrieved	6,400	–
Subject filter: Business, Management, Accounting	4,880	1,520
Article type: Articles and Reviews only	3,970	910
Language: English only	3,540	430
Final screening: title, abstract, metadata	3,223	317
Source(s): Authors' work		

Pre-processing consisted of:

1. Lowercasing – Converted text to lowercase for normalising text (Manning *et al.*, 2008).
2. Noise Removal – Removed punctuation, special characters, email addresses, and URLs using regular expressions (Bird *et al.*, 2009).
3. Lemmatisation – Used the spaCy English core model to lemmatise words to their lemmas (Honnibal, 2017).
4. Stopword removal – Removing English stop words to minimise semantic noise.
5. Token filtering – Keeping only alphabetic tokens of at least three characters to maximise topic clarity (Zhang *et al.*, 2010).

The processed corpus is stored in a.csv file containing the original metadata (*title*, *abstract*, *publication year*) and the cleaned, lemmatised text. This file (*merged_clean.csv*) functioned as the input for the following topic modelling phase.

2.3 Topic modelling framework

To extract themes from the collected corpus, we used BERTopic, (Grootendorst, 2022), an unsupervised framework which combines transformer-based embeddings, manifold learning, and density-based clustering. Unlike traditional models such as LDA, BERTopic uses sentence embeddings rather than word-level co-occurrence, enabling high-dimensional representations.

2.3.1 Document representation using sentence embeddings. Each document $d_i \in D = \{d_1, d_2, \dots, d_n\}$ was embedded into a high-dimensional space using a MiniLM-L6-v2 transformer model, a variant of BERT designed for speed and performance. (Microsoft Research, 2021). Document representations take the format:

$$x_i = \text{MiniLM}(d_i) \in \mathbb{R}^{384}$$

Cosine similarity, $\text{sim}(x_i, x_j)$, reflects contextual proximity between vectors (Reimers and Gurevych, 2019).

2.3.2 Dimensionality reduction with UMAP. These 384-dimensional embeddings were reduced using Uniform Manifold Approximation and Projection (UMAP), which holds both global and local data structure. (McInnes *et al.*, 2020). UMAP minimises cross-entropy between high and low-dimensional spaces by learning a transformation with the following formula:

$$f: \mathbb{R}^{384} \rightarrow \mathbb{R}^k, \text{ where } k = 10$$

Parameters used:

$n_neighbors = 25$

n_components = 10

min_dist = 0.05

Distance metric: cosine

This step improves clustering while maintaining semantic fidelity.

2.3.3 Density-based clustering with HDBSCAN. We applied HDBSCAN to the UMAP-reduced vectors, a noise-aware algorithm for uneven density data (Campello and Moulavi, 2013; McInnes et al., 2017). It creates a mutual reachability graph and outputs:

$$C : R_k \rightarrow \{0, 1 \dots, T, -1\}$$

where -1 denotes noise (un-clustered documents).

A grid search was run across:

min_cluster_size $\in \{5, 10, 15 \dots, 40\}$

min_samples $\in \{5, 10, 15, 20, 25\}$

Each configuration registered the number of topics T and the outlier percentage $(n - 1/n) \times 100$. The final manually selected model from Table 3 yielded 18 topics with an outlier rate of 43.05%, optimising coverage and thematic granularity.

The final selected configuration used min_cluster_size = 15 and min_samples = 10, producing 18 coherent topics and achieving an optimal balance between topic granularity and outlier rate.

The selected configuration yielded an outlier rate of 43.05%. Documents assigned a -1-cluster label were excluded from topic assignment. This proportion may appear elevated relative to traditional benchmarks. However, it is consistent with BERTopic applications on heterogeneous academic corpora. Sustainable tourism research is inherently interdisciplinary. It spans behavioural science, environmental policy, hospitality management, and ecological planning. Documents at the intersection of multiple domains often resist clean cluster assignment. Excluding such documents is both statistically expected and methodologically appropriate. Forcing them into the nearest cluster would artificially inflate topic coherence scores. It would also introduce thematic noise into each cluster's representative keywords. Comparable BERTopic studies on multidisciplinary corpora report outlier rates of 35%–55%. Higher exclusion rates are often associated with improved topic granularity (Grootendorst, 2022; Gilardi et al., 2023). A sensitivity analysis was conducted across 25 HDBSCAN parameter combinations, as shown in Table 3. Configurations with fewer topics produced higher outlier rates without improving coherence, whereas configurations with more topics introduced redundant or overlapping clusters. The selected configuration, therefore, represents a balanced trade-off. It optimises topic granularity, cluster coverage, and interpretive clarity. This produces a stable, reproducible thematic structure for subsequent SDG alignment and forecasting analyses.

Table 3 Top 5 parameter combinations from HDBSCAN grid search

min_cluster_size	min_samples	Topics	Outliers	Outlier percent
5	5	103	1,520	47.18
5	10	49	1,539	47.77
5	15	38	1,742	54.07
5	20	29	1,864	57.85
5	25	21	1,558	48.36

Source(s): Authors' work

2.3.4 Topic representation using c-TF-IDF. To represent and label each topic, class-based TF-IDF (c-TF-IDF) was used, which modifies traditional TF-IDF by treating each topic t as a “class”. For a term w in topic t , c-TF-IDF is computed as:

$$\text{c-TF-IDF}_{t,w} = \left(\frac{\sum f_{t,w}}{\sum_w f_{t,w}} \right) \cdot \log(N/\text{df}_w)$$

Where:

$f_{t,w}$ = frequency of word w in topic t .

N = total number of topics

df_w = number of topics where w appears

This score highlights words that are precise to a topic but rare across others.

2.3.5 Topic labelling with GPT-4. To enhance topic interpretability, we employed GPT-4, a large language model developed by [Achiam et al. \(2023\)](#). Using prompt engineering, we fed GPT-4 with each topic’s top-ranked keywords and representative documents to generate concise, human-readable topic labels. All AI-generated labels were manually reviewed to ensure relevance, consistency, and domain alignment ([Gilardi et al., 2023](#)). This hybrid approach offered both semantic precision and computational efficiency. Final outputs are summarised in [Table 4](#).

2.3.6 Manual SDG mapping. The Sustainable Development Goals (SDGs), set by the United Nations under the 2030 Agenda, act as a global framework for promoting social, economic, and environmental priorities ([UN, 2015](#)). In this study, six SDGs were most suitable for sustainable tourism research:

SDG 8: Decent Work and Economic Growth

SDG 11: Sustainable Cities and Communities

SDG 12: Responsible Consumption and Production

SDG 13: Climate Action

SDG 15: Life on Land

SDG 17: Partnerships for the Goals

To align topics with the SDGs, we manually mapped each topic generated by BERTopic ([Grootendorst, 2022](#)). This process involved reviewing:

1. Top-ranked keywords from c-TF-IDF
2. Representative documents in each cluster
3. GPT-4-improved topic labels ([Achiam et al., 2023](#))

Each topic was assigned SDGs based on thematic applicability. Differences are fixed through discussion, following qualitative coding practices ([Saldaña, 2021](#)). Unlike automated keyword-based classifiers, this method allowed for deeper contextual alignment. Final mappings were compiled into a CSV file (topic_info_sdg.csv) and used in subsequent analyses to assess SDG coverage and identify underrepresented goals. [Table 4](#) presents the final SDG-topic associations.

2.3.7 Temporal trend analysis and forecasting. To understand how research themes have evolved, we utilised BERTopic’s built-in topics_over_time method ([Grootendorst, 2022](#)). This

Table 4 Topic summary with frequencies and c-TF-IDF-based labels

Topic	Generated name (c-TF-IDF)	LLM-generated topic name	Count
0	tourist_tourism_intention_behavior	Tourist Behaviour and Travel Intention	298
1	hotel_green_practice_industry	Green Practices in the Hotel Industry	229
2	stakeholder_tourism_sustainable_sustainability	Stakeholder Engagement in Sustainable Tourism	137
3	tourism_sustainable_climate_development	Climate-Oriented Sustainable Tourism Development	133
4	emission_carbon_energy_tourism	Carbon Emissions and Energy Management in Tourism	111
5	indicator_policy_tourism_sustainable	Sustainability Indicators and Policy Frameworks	111
6	smart_tourism_research_analysis	Smart Tourism Technologies and Research Trends	91
7	coordination_development_ecological_spatial	Ecological Coordination and Spatial Planning	82
8	covid_pandemic_tourism_crisis	Impact of COVID-19 on Tourism Systems	76
9	resilience_risk_disaster_tourism	Disaster Resilience and Risk Management in Tourism	72
10	heritage_cultural_site_urban	Cultural Heritage and Urban Tourism	68
11	diving_marine_coastal_surf	Coastal and Marine Tourism Activities	65
12	water_waste_circular_management	Circular Economy in Water and Waste Management	64
13	rural_agritourism_community_development	Rural and Community-Based Agritourism	59
14	education_student_educational_sustainability	Sustainability Education in Tourism	46
15	tourist_destination_willingness_pay	Tourist Willingness to Pay and Destination Choice	45
16	area_park_development_tourism	National Parks and Protected Area Tourism	44
17	ecotourism_geotourism_conservation_development	Ecotourism and Geotourism for Conservation	42
18	fuzzy_model_tourism_propose	Tourism Modelling and Fuzzy Decision Approaches	38

Source(s): Authors' work

function aggregates topic frequency over discrete time intervals derived from document publication years. The temporal resolution was set to yearly to preserve annual changes.

Let $T = \{t_1, t_2, \dots, t_k\}$ be the set of discovered topics and $Y = \{y_1, y_2, \dots, y_n\}$ be the corresponding publication years. A topic frequency matrix $F \in \mathbb{Z}^+(K \times n)$ was computed, where:

$F[k, y]$ = number of documents assigned to topic t_k in year y .

This matrix was visualised using topic-wise line plots and temporal heatmaps to highlight emerging or declining trends in sustainable tourism.

To forecast future topic trends, we employed the Prophet model, an open-source time-series forecasting tool developed by Facebook (Taylor and Letham, 2018). For each topic t , a univariate time series was constructed:

$\{(y, f[k, y])\}$, where $f[k, y]$ is the frequency of topic t in year y .

Prophet fits an additive model of the form:

$$y(t) = g(t) + s(t) + h(t) + \epsilon t$$

Where:

$g(t)$: piecewise linear trend

$s(t)$: yearly seasonality (optional)

$h(t)$: holiday effects (not used in this study)

ϵt : error term

The model was trained on historical data to forecast topic prevalence through 2030, providing predictive insights into research courses. Results were exported as CSV files and visualised via Plotly line charts. Also, a combined forecast across all topics was generated for comparative trend analysis. This step adds forward-looking value by enabling researchers and policymakers to predict shifts in academic focus areas related to sustainability and tourism.

3. Topic modelling of sustainable tourism narratives through BERTopic

The BERTopic model applied to the pre-processed corpus identified 18 interpretable thematic clusters based on contextual similarity across academic abstracts and titles. Each topic is characterised by a representative label generated through class-based Term Frequency–Inverse Document Frequency (c-TF-IDF), which highlights terms that are distinctively associated with a given cluster relative to the broader corpus. This approach produces interpretable topic profiles grounded in the most statistically discriminating keywords within each theme.

[Table 4](#) summarises the identified topics, including their numeric identifiers, document counts, and semantically enriched labels derived through a hybrid c-TF-IDF and GPT-4 labelling process. For each topic, the top-ranked keywords and a representative sample of associated publications were extracted and provided to GPT-4 using the following structured prompt:

You are a domain expert in sustainable tourism. Based on the following keywords and document snippets, suggest a short, academic-style topic name (5–10 words) that best summarises the theme. Avoid generic phrases. Keywords: [insert top keywords]. Sample text: [insert top document titles or abstracts].

All AI-generated labels were subsequently reviewed and refined through manual assessment to ensure thematic clarity, eliminate redundancy, and maintain consistency across topics. This human-in-the-loop approach balances algorithmic objectivity with domain expertise, resulting in the semantically meaningful labels presented in [Table 4](#).

3.1 Alignment of sustainable tourism topics with the SDGs

Each of the 18 identified topics was systematically mapped to relevant Sustainable Development Goals through a structured manual coding process. The mapping drew on three sources of evidence for each topic: the top-ranked c-TF-IDF keywords, a representative subset of documents from each cluster, and the GPT-4-generated topic label. SDG assignments were determined based on thematic applicability and cross-validated through discussion among the research team, following established qualitative coding practices ([Saldaña, 2021](#)). Unlike automated keyword-based classifiers, this approach enables deeper contextual alignment between research themes and SDG targets. Final mappings were recorded in a structured CSV file and used in subsequent analyses to assess SDG coverage and identify underrepresented goals. [Table 5](#) presents selected document-level alignments illustrating the mapping process, and the individual topic discussions below provide detailed rationales for each SDG assignment.

3.1.1 Topic 0: tourist behaviour and travel intention. Research within this cluster examines tourist decision-making, sustainable behavioural intentions, and the determinants of environmentally

Table 5 Mapping topics to relevant SDGs based on document classification

Topic	Title
12	Environmental Sustainability and Carbon Footprint of Tourism: A Study of a Natural Park in Northeastern Kazakhstan
2	Evaluation of Sustainable Tourism Development in Dachen Island, East China Sea: Stakeholders' Perspective
4	Linking tourists' footprint and environmental tragedy through transportation, globalisation, and energy choice in the BIMSTEC region
4	The Impact of Green Finance on Renewable Energy Development in India's Tourism Industry
2	Sustainable Tourism Development: How Do Destination Stakeholders Perceive Sustainable Urban Tourism?
12	Tackling Water and Waste Management Challenges Within the Tourism and Hospitality Industry: A Sustainable Development Goals Perspective
5	How to use a composite indicator and a linear programming model to determine sustainable tourism

Source(s): Authors' work

responsible travel choices. Studies in this area predominantly apply behavioural frameworks such as the Theory of Planned Behaviour and the Value-Belief-Norm Theory to model the psychological antecedents of sustainable consumption (Ajzen, 1991; Stern *et al.*, 1999). The cluster aligns with SDG 12 (Responsible Consumption and Production), as sustainable tourism fundamentally begins with individual consumption decisions, and with SDG 13 (Climate Action), through studies examining green destination selection, carbon footprint reduction, and climate-conscious travel behaviour.

3.1.2 Topic 1: green practices in the hotel industry. This cluster addresses environmentally responsible operational practices within the hospitality sector, encompassing green certifications, eco-efficient supply chain management, and sustainable facility operations. Practices such as energy-efficient lighting, water-saving infrastructure, and zero-waste programs align with SDG 12, while reducing carbon emissions and energy consumption directly support SDG 13. Additionally, as the hospitality industry is among the world's largest employers, integrating sustainability into workforce training and service delivery contributes to SDG 8 (Decent Work and Economic Growth) by improving innovation and employment quality (World Tourism Organization (UNWTO) and United Nations Development Programme (UNDP), 2017).

3.1.3 Topic 2: stakeholder engagement in sustainable tourism. This topic covers participatory approaches to sustainable tourism development, including co-management frameworks, multi-stakeholder governance systems, and local community involvement in destination planning. The emphasis on cross-sectoral and institutional collaboration aligns with SDG 17 (Partnerships for the Goals). At the same time, incorporating local stakeholder needs into tourism policy supports SDG 11 (Sustainable Cities and Communities) by promoting planning processes that respect cultural heritage and encourage inclusive urban development (Bramwell and Lane, 2011).

3.1.4 Topic 3: climate-oriented sustainable tourism development. This cluster examines the bidirectional relationship between tourism and climate change, with a focus on adaptation and mitigation strategies in destination planning. Key research areas include carbon offsetting schemes, climate-resilient infrastructure, and transition planning for sustainable tourism destinations. These themes align closely with SDG 13 (Climate Action). At the same time, climate-resilient infrastructure development connects to SDG 11, and innovation through sustainable design links to SDG 9 (Industry, Innovation and Infrastructure) (Becken and Hay, 2007).

3.1.5 Topic 4: carbon emissions and energy management. This cluster addresses the quantification, monitoring, and reduction of tourism-related emissions, with a particular focus on transport and hospitality operations. Carbon footprint measurement, energy auditing, and renewable energy integration are among the primary research contributions, directly supporting SDG 13 (Climate Action). Research emphasising the transition to renewable energy systems also engages SDG 7 (Affordable and Clean Energy). This technically oriented cluster provides evidence-based tools and frameworks for decarbonising tourism systems and informing sustainability policy (Gössling and Peeters, 2015).

3.1.6 Topic 5: sustainability indicators and policy frameworks. Research in this cluster develops and evaluates sustainability measurement tools for tourism policy, encompassing sustainability indicators, multi-criteria evaluation instruments, and performance benchmarking procedures. These instruments support SDG 12 (Responsible Consumption and Production) by enabling systematic tracking of environmental impacts and resource efficiency (World Tourism Organization (UNWTO) and United Nations Development Programme (UNDP), 2017). The development of participatory governance instruments and regulatory frameworks further aligns with SDG 16 (Peace, Justice and Strong Institutions) by promoting accountable and inclusive institutional mechanisms (UN, 2015).

3.1.7 Topic 6: smart tourism technologies and research trends. This cluster examines the application of digital technologies and data-driven systems in sustainable tourism management, including IoT-based destination monitoring, artificial intelligence for travel optimisation, and big data analytics platforms. These innovations align with SDG 9 (Industry, Innovation and Infrastructure) through their contribution to smart, resilient infrastructure (Gretzel *et al.*, 2015). By enabling real-time congestion management, efficient transport coordination, and data-informed urban planning, this topic also supports SDG 11 (Sustainable Cities and Communities).

3.1.8 Topic 7: ecological coordination and spatial planning. This theme encompasses research on the spatial coordination of tourism development and environmental conservation, including GIS-based land-use modelling, ecological zoning, and strategic protected area management. These areas align with SDG 15 (Life on Land), which seeks to halt biodiversity loss and ensure ecosystem conservation (UNEP-WCMC, 2020). The integration of tourism with spatial planning further supports SDG 11 by facilitating sustainable urban-rural development and preventing the encroachment of tourism infrastructure into ecologically sensitive zones.

3.1.9 Topic 8: impact of COVID-19 on tourism systems. This cluster analyses the multidimensional effects of the COVID-19 pandemic on tourism systems, including labour market disruption, crisis recovery strategies, and health policy responses. The topic aligns with SDG 8 (Decent Work and Economic Growth) through its focus on unemployment, informal employment vulnerability, and economic exposure in pandemic-affected tourism economies (Brozović and Saito, 2022), and with SDG 3 (Good Health and Well-being) through biosecurity and wellness tourism research. The transnational character of the crisis and the importance of multilateral recovery coordination further connect this cluster to SDG 17 (Partnerships for the Goals).

3.1.10 Topic 9: disaster resilience and risk management in tourism. Research in this cluster addresses the development of destination resilience and risk management capacity against environmental and anthropogenic hazards. Studies focus on crisis management planning, risk perception frameworks, early warning systems, and adaptive strategies for tourism destinations. These themes align directly with SDG 11 (Sustainable Cities and Communities) through disaster-vulnerability-reduction targets, and with SDG 13 (Climate Action) through climate-related risk research encompassing flooding and extreme weather events, and through the development of adaptive capacity in tourism planning (Becken and Hughey, 2013).

3.1.11 Topic 10: cultural heritage and urban tourism. This cluster examines the relationship between urban tourism and cultural heritage, focusing on heritage preservation, urban revitalisation, and the authenticity of tourist experiences. The primary alignment is with SDG 11 (Sustainable Cities and Communities), specifically Target 11.4, which calls for the protection of cultural and natural heritage (UNESCO, 2016). Research on community-based preservation and participatory planning further connects this topic to SDG 4 (Quality Education, Target 4.7), while heritage tourism's employment generation in crafts, guiding, and site management aligns with SDG 8 (Decent Work and Economic Growth) (UNEP, 2021).

3.1.12 Topic 11: coastal and marine tourism activities. This cluster addresses sustainable management practices in coastal and marine tourism, including recreational diving, marine conservation, and coastal zone governance. The alignment with SDG 14 (Life Below Water) is most direct, particularly regarding the conservation of marine ecosystems and the sustainable use of ocean resources (UNEP, 2021). Studies examining the impacts of tourist behaviour on marine environments and promoting sustainable recreational practices, including waste minimisation, reef-friendly product use, and eco-certification of operators, further connect this topic to SDG 12 (Responsible Consumption and Production) (Garrod and Gossling, 2007).

3.1.13 Topic 12: circular economy in water and waste management. This topic addresses the application of circular economy principles to water use, waste reduction, and sanitation within tourism establishments. Key interventions include wastewater recycling, solid waste minimisation, and greywater reuse systems. These practices align directly with SDG 12 (Responsible Consumption and Production) through resource-efficiency and waste-management targets, and with SDG 6 (Clean Water and Sanitation) through research on sustainable water conservation and pollution prevention (European Commission, 2020).

3.1.14 Topic 13: rural and community-based agritourism. This cluster centres on agricultural, cultural, and community-oriented rural tourism models, with research priorities including livelihood diversification, local entrepreneurship, and the design of authentic cultural experiences. The promotion of sustainable rural settlements connects this topic to SDG 11 (Sustainable Cities and Communities), while rural economic growth through tourism aligns with SDG 8 (Decent Work and Economic Growth) (FAO, 2020). Where sustainable agricultural practices and low-impact operations are integrated, this topic also engages SDG 15 (Life on Land) through biodiversity protection and sustainable land use.

3.1.15 Topic 14: sustainability education in tourism. This cluster addresses the integration of sustainability principles into tourism education and professional capacity development. Primary research areas include curriculum design, environmental literacy initiatives for tourists, and vocational training for tourism practitioners. The strongest alignment is with SDG 4 (Quality Education, Target 4.7), which promotes education for sustainable development and global citizenship (UNESCO, 2016). By embedding sustainability into tourism pedagogy and practitioner training, this topic indirectly supports SDG 12 and SDG 13 by increasing awareness and driving behavioural change.

3.1.16 Topic 15: tourist willingness to pay and destination choice. This cluster examines tourists' willingness to pay premium prices for sustainable tourism products, eco-certified experiences, and conservation contributions, alongside the behavioural economics of environmentally responsible destination selection. The emphasis on responsible consumption patterns and premium payment for sustainable services aligns with SDG 12 (Responsible Consumption and Production). Through its support for eco-friendly destination choice and the economic viability of sustainable service providers, this topic also connects to SDG 8 (Decent Work and Economic Growth) by demonstrating market-based pathways to inclusive economic growth within host communities.

3.1.17 Topic 16: national parks and protected area tourism. This cluster addresses tourism within protected landscapes, including national parks, wildlife sanctuaries, and ecologically sensitive zones. Research themes encompass visitor impact management, conservation tourism models, and infrastructure planning for natural reserves. The topic aligns most directly with SDG 15 (Life on Land) through biodiversity conservation and sustainable ecosystem management targets. The promotion of responsible visitation and low-impact recreation further supports SDG 11 (Sustainable Cities and Communities). At the same time, the application of nature-based solutions for climate resilience connects this cluster to SDG 13 (Climate Action).

3.1.18 Topic 17: ecotourism and geotourism for conservation. This topic covers the principles and practices of ecotourism and geotourism, emphasising low-impact travel, environmental education, and the conservation of natural habitats. It aligns strongly with SDG 15 (Life on Land) and SDG 13 (Climate Action) by promoting travel models that prioritise conservation over resource exploitation. Community participation and benefit-sharing arrangements featured within this cluster further connect it to SDG 8 (Decent Work and Economic Growth) and SDG 10 (Reduced Inequalities) by positioning ecotourism as a source of alternative livelihoods and more equitable economic development.

3.1.19 Topic 18: tourism modelling and fuzzy decision approaches. This methodologically oriented cluster applies multi-criteria decision-making, fuzzy logic modelling, and computational optimisation techniques to tourism planning and sustainability analysis. Its applications target resource allocation, environmental performance ranking, and evidence-based policy evaluation. The use of data-driven innovation aligns with SDG 9 (Industry, Innovation and Infrastructure), while applications that assess carbon trade-offs and ecological risks further connect this cluster to SDG 13 (Climate Action) and SDG 12 (Responsible Consumption and Production).

3.2 Summary of topics – SDG mapping

The individual topic analyses presented above demonstrate clear and substantiated connections between each of the 18 identified research themes and one or more Sustainable Development Goals. Beyond establishing conceptual alignment, this mapping provides strategic insight into how sustainable tourism scholarship collectively supports the 2030 Agenda, identifying both the SDGs most thoroughly addressed by existing research and those requiring greater scholarly attention. The resultant topic labels and their corresponding SDG alignments are summarised in [Table 6](#), with SDG frequency across topics visualised in [Figure 2](#).

This figure illustrates the frequency with which each Sustainable Development Goal (SDG) was mapped across the 18 recognised research themes in the sustainable tourism literature. SDG 12 (Responsible Consumption) and SDG 13 (Climate Action) were the most prominent, suggesting strong environmental and behavioural exposure in the current academic discourse.

4. Temporal analysis of sustainable tourism using BERTopic modelling

4.1 Inter-topic distance map: visualising the semantic landscape of research themes

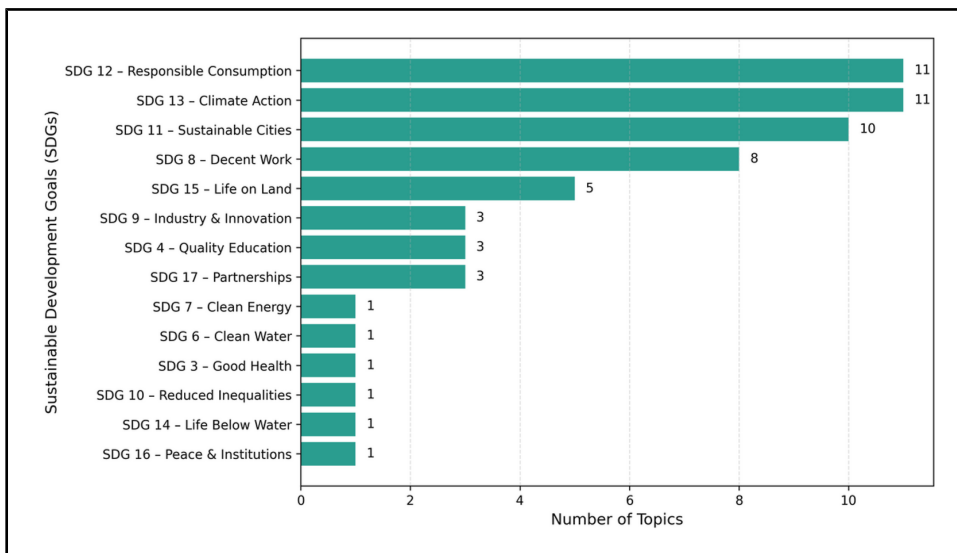
To improve the interpretability of the 18 identified topics and facilitate exploration of their structural relationships, a series of static and interactive visualisations was generated using BERTopic's built-in modules. These visualisations provide insight into the distribution, semantic overlap, and keyword composition of the identified research themes. Analysis of the inter-topic distance map identified four semantically integrated regions that reflect the underlying thematic architecture of sustainable tourism research.

4.1.1 Consumer behaviour core. Topic 15 (Willingness to Pay) is nested within Topic 0 (Tourist Behaviour and Intention), indicating substantial overlap between behavioural economics and

Table 6 Final mapping of research topics to sustainable development goals

Topic	LLM-generated topic name	Mapped SDGs
0	Tourist Behaviour and Travel Intention	SDG 12, SDG 13
1	Green Practices in the Hotel Industry	SDG 8, SDG 12, SDG 13
2	Stakeholder Engagement in Sustainable Tourism	SDG 11, SDG 17
3	Climate-Oriented Sustainable Tourism Development	SDG 11, SDG 13
4	Carbon Emissions and Energy Management in Tourism	SDG 7, SDG 13
5	Sustainability Indicators and Policy Frameworks	SDG 12, SDG 16
6	Smart Tourism Technologies and Research Trends	SDG 9, SDG 11
7	Ecological Coordination and Spatial Planning	SDG 11, SDG 15
8	Impact of COVID-19 on Tourism Systems	SDG 3, SDG 8, SDG 17
9	Disaster Resilience and Risk Management in Tourism	SDG 11, SDG 13
10	Cultural Heritage and Urban Tourism	SDG 4, SDG 8, SDG 11
11	Coastal and Marine Tourism Activities	SDG 12, SDG 14
12	Circular Economy in Water and Waste Management	SDG 6, SDG 12
13	Rural and Community-Based Agritourism	SDG 8, SDG 11, SDG 15
14	Sustainability Education in Tourism	SDG 4, SDG 12, SDG 13
15	Tourist Willingness to Pay and Destination Choice	SDG 8, SDG 12
16	National Parks and Protected Area Tourism	SDG 11, SDG 13, SDG 15
17	Ecotourism and Geo tourism for Conservation	SDG 8, SDG 10, SDG 13, SDG 15
18	Tourism Modelling and Fuzzy Decision Approaches	SDG 9, SDG 12, SDG 13

Source(s): Authors' work

Figure 2 Frequency of SDG alignment across extracted research topics.
Source: Authors' work

psychologically oriented sustainability models such as the Theory of Planned Behaviour and Value-Belief-Norm Theory (Ajzen, 1991; Han *et al.*, 2010). This cluster converges with SDGs 12 and 13 by examining how personal consumer decisions advance sustainable consumption and climate-conscious travel behaviour.

4.1.2 Cultural and place-based convergence. Topics 16 (National Parks) and 10 (Cultural Heritage) converge on themes of place identity and destination authenticity (UNESCO, 2016). Topic 17 (Ecotourism) bridges the natural and cultural dimensions of this cluster, illustrating how conservation ethics span both heritage and nature-based tourism contexts (Garrod and Gossling, 2007).

4.1.3 Policy, risk, and governance. This semantically dense region comprises Topics 2, 3, 5, 6, 8, 9, 13, 15, and 18, collectively addressing stakeholder governance, crisis adaptation, sustainability measurement, and decision-support systems. These topics represent an integrated governance narrative spanning COVID-19 crisis response, disaster risk frameworks, smart tourism infrastructure, and computational modelling approaches, all consistent with SDG 11, SDG 13, and SDG 17 (UN, 2015).

4.1.4 Operations and environmental practices. Topics 1, 4, 7, 11, and 12 collectively represent operational-level sustainability innovations, encompassing green hotel practices, carbon auditing, marine resource conservation, ecological land management, and wastewater reuse systems (European Commission, 2020; UNEP, 2021). This super-topic aligns most directly with SDG 12 and SDG 13 and reflects the operational core of sustainable tourism's environmental performance management landscape.

Figure 3 presents the UMAP-based inter-topic distance map with all 18 research themes annotated with LLM-generated labels and arranged according to semantic similarity in a reduced vector space.

4.2 Topic-wise keyword representation via c-TF-IDF bar chart

Figure 4 displays the most distinctive keywords for each topic, ranked by c-TF-IDF scores. These scores are computed to identify terms that are statistically characteristic of a given topic while being comparatively rare across the broader corpus. Each bar represents a keyword's relative

Figure 3 Intertopic distance map. Source: Authors' work

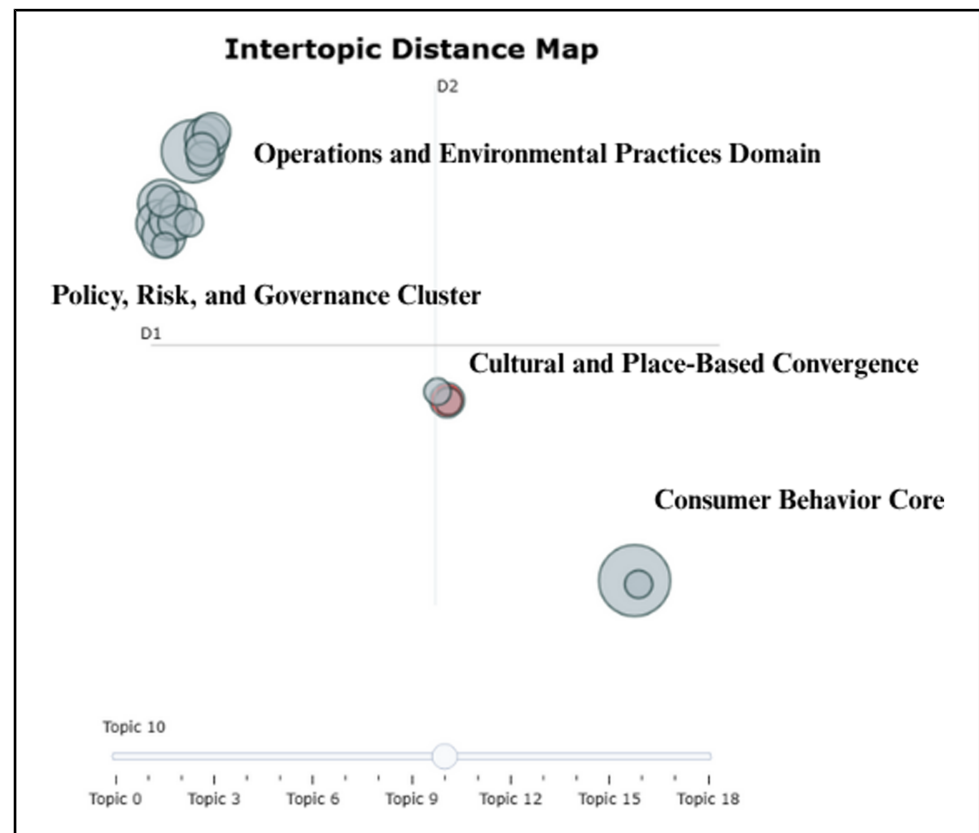
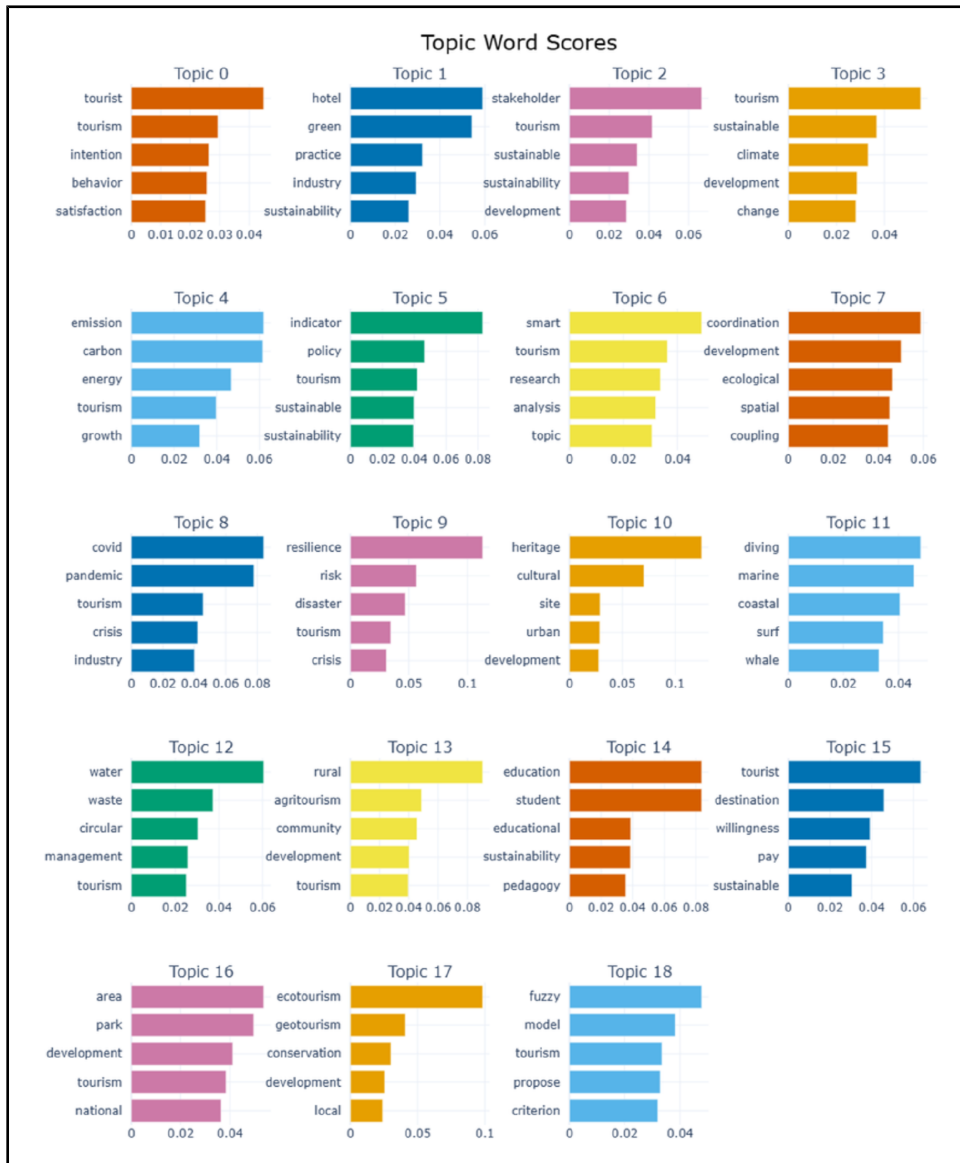


Figure 4 Top keywords per topic (via c-TF-IDF ranking). Source: Authors' work



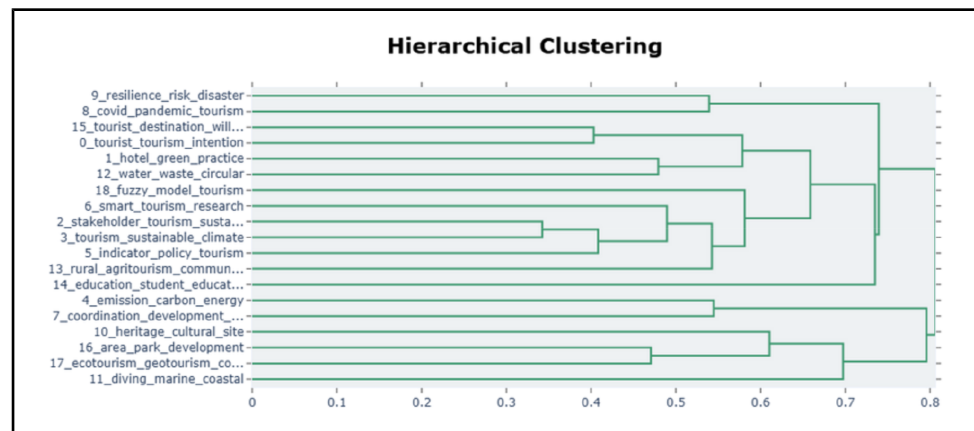
discriminatory importance within its corresponding topic, with rankings following a characteristic decline curve reflecting diminishing marginal information gain.

4.3 Hierarchical topic structure represented by dendrogram

Figure 5 presents a hierarchical clustering of the 18 identified topics based on their semantic similarity, computed from c-TF-IDF vector representations. The dendrogram reveals parent-child thematic relationships and latent super-topic structures, indicating which topics share sufficient lexical and conceptual proximity to be grouped under higher-level thematic categories. This tree-based perspective complements the UMAP projection in Figure 3 by providing a structured, interpretable view of inter-topic proximity.

Topics 2 (Stakeholder Engagement), 3 (Climate-Oriented Tourism), and 5 (Sustainability Indicators) are closely clustered, reflecting their shared emphasis on governance, planning,

Figure 5 Hierarchical structure of topics based on semantic similarity.
Source: Authors' work



and policy-related dimensions of sustainable tourism. In contrast, Topics 10 (Cultural Heritage) and 13 (Rural Community Agritourism) align with a broader place-based tourism theme, consistent with earlier insights from the topic map. More technically oriented topics, such as Topic 18 (Fuzzy Modelling) and Topic 6 (Smart Tourism Technologies), are positioned farther from behavioural or destination-focused themes, highlighting their roles in distinct research sub-streams. This hierarchical structure not only reveals latent super-topics within the corpus but also underscores how technically nuanced themes can emerge within the overarching framework of sustainable tourism.

4.4 Heatmap visualisation of topic distribution

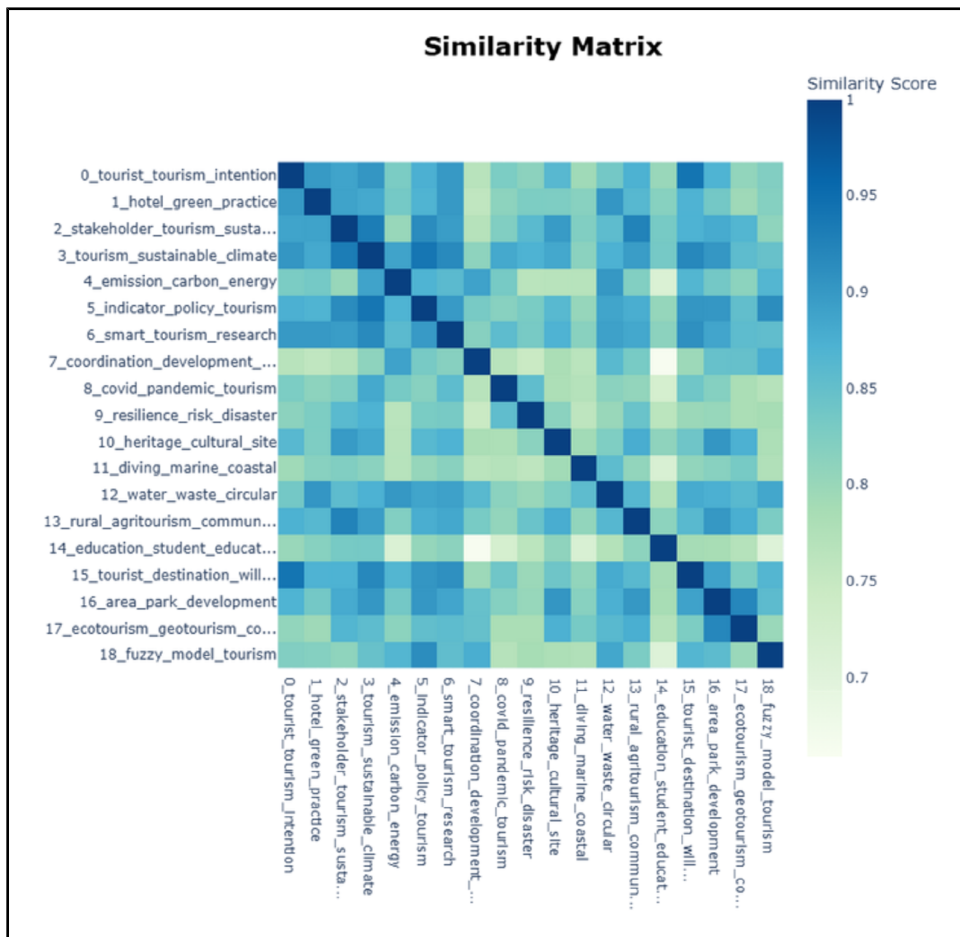
Figure 6 presents a pairwise similarity heatmap of all 18 topics, computed from their c-TF-IDF representations. Each cell reflects the degree of keyword overlap or semantic proximity between two topics, with brighter cells indicating higher similarity and darker cells indicating greater thematic distinctiveness. This visualisation helps identify potentially redundant clusters, opportunities for topic merging, and shared vocabularies across thematic domains.

Two relationships are particularly pronounced. First, Topics 0 (Tourist Behaviour and Intention) and 15 (Willingness to Pay) exhibit very high semantic similarity, as reflected in one of the lightest cells in the heatmap. This overlap is consistent with their shared conceptual foundation in tourist psychology, valuation behaviour, and sustainable decision-making frameworks. Second, Topics 7 (Ecological Coordination and Spatial Planning) and 14 (Sustainability Education in Tourism) display among the highest dissimilarities in the matrix, reflecting their positioning in distinct disciplinary spaces: physical planning and ecological science on one hand, and pedagogy and educational practice on the other.

4.5 Visualisation of term score distribution within topics

Figure 7 illustrates the rate at which keyword importance, measured by c-TF-IDF score, declines within each topic. A steep decline indicates a narrowly defined, lexically focused topic with a small set of highly discriminating terms. A more gradual slope reflects a broader, more conceptually diffuse theme, with a wider, more distributed keyword structure. These term-rank decline patterns help evaluate the semantic sharpness and vocabulary coherence of individual topics.

Figure 6 Inter-topic similarity heatmap based on keyword overlap. Source: Authors' work

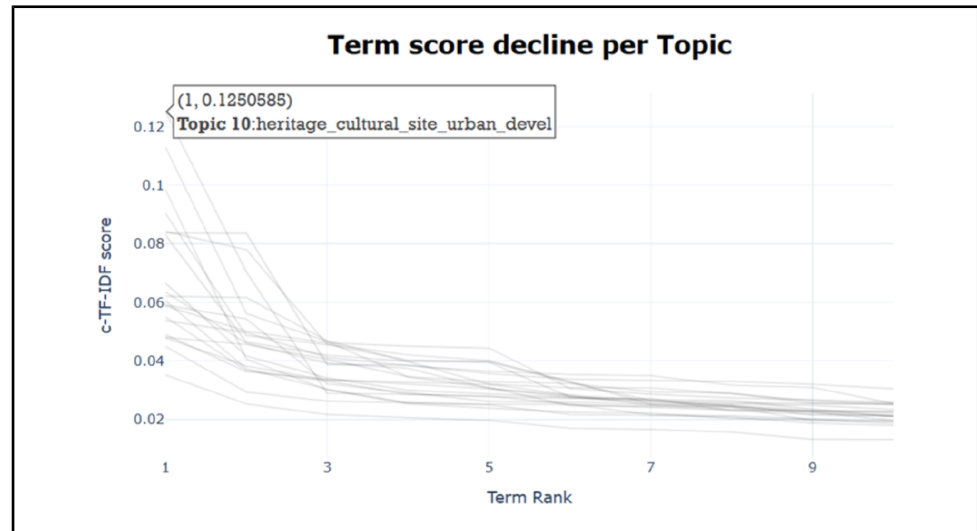


Two distinct patterns are evident. Topics 9 (Disaster Resilience and Risk Management) and 10 (Cultural Heritage and Urban Tourism) exhibit the sharpest term-rank decline slopes, indicating high semantic focus and well-defined topical boundaries, characterised by a concentrated cluster of high-weight discriminating terms. In contrast, Topic 2 (Stakeholder Engagement in Sustainable Tourism) demonstrates a more gradual slope, reflecting its broader and more conceptually dispersed vocabulary, consistent with its wide thematic coverage spanning governance structures, community planning, and multi-stakeholder sustainability implementation.

5. Predictive analysis of sustainable tourism trends with BERTopic

Despite the growth of topic modelling in tourism research, most earlier studies used static methods such as LDA or NMF, emphasising cross-sectional theme extraction (Egger and Yu, 2022). Few have examined temporal changes in research themes in sustainable tourism using dynamic models, and, to the best of our knowledge, none have combined BERTopic with predictive models such as Prophet to forecast the popularity of future topics within an SDG-aligned sustainable tourism corpus. Dynamic topic modelling approaches such as Topics over Time and dynamic LDA have been applied in adjacent fields using generative Bayesian or autoregressive models rather than embedding-based approaches (Blei and Lafferty, 2006; Dubey et al., 2013; Cendrero et al., 2025). Tourism demand forecasting has similarly relied on predictive models targeting visitor volumes, such as LSTM and hybrid BiLSTM-Transformer

Figure 7 Term rank decline plot based on keyword importance. Source: Authors' work



systems, rather than tracking shifts in thematic focus within academic production (Yiet *et al.*, 2021). This study addresses that gap by combining BERTopic's temporal outputs with Prophet-based forecasting, transforming static topic modelling into a forward-looking analytical instrument that enables retrospective tracking and strategic foresight into how scholarly attention toward primary sustainability issues evolves.

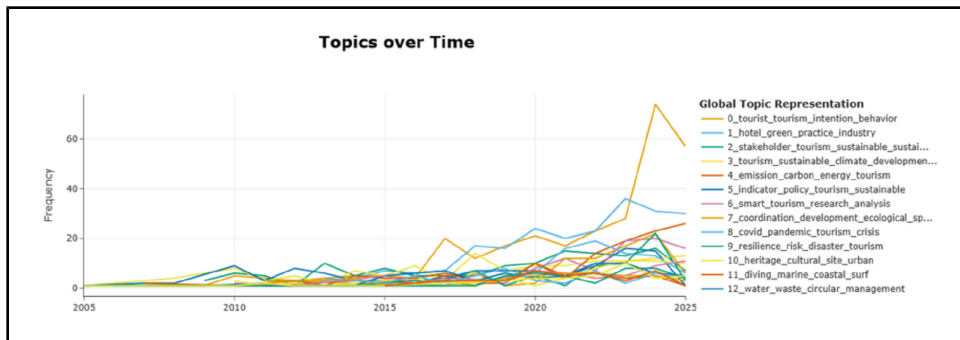
5.1 Evolutionary trends over the period

The Topic Trendlines (Figure 8) illustrate how the prevalence of each topic has evolved year by year across the dataset, generated using BERTopic's `topics_over_time` method, which maps each document's publication year onto its assigned topic cluster to construct a temporal frequency path for each research theme. Each line represents the annual publication volume for a given topic, with smoother curves reflecting aggregated temporal bins and peaks indicating concentrated surges in academic attention.

5.1.1 Topic 0 (tourist behaviour and intention). A steep and sustained rise between 2022 and 2024 reflects growing scholarly interest in post-pandemic behavioural transformation, sustainable consumption habits, and AI-driven personalisation within tourism systems. Research has established that the pandemic considerably reshaped tourist priorities, with safety consciousness, sustainability awareness, and digital convenience emerging as dominant decision-making factors. This growth trajectory aligns directly with SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action), as researchers increasingly examine how recommender systems, eco-labelling frameworks, and digital nudging mechanisms can systematically steer tourists toward lower-impact travel decisions. From a performance management perspective, the expansion of this research stream signals growing demand for behavioural sustainability metrics, including eco-friendly booking rates, carbon-conscious destination selection indices, and digital engagement indicators that tourism organisations can embed within their sustainability monitoring systems.

5.1.2 Topic 1 (green practices in hotels). This historically dominant theme has shown signs of levelling off since 2022, suggesting that operational sustainability research is maturing. Foundational concepts, including energy-efficient infrastructure, waste-reduction programs, and green certification systems, have progressively been institutionalised within the hospitality

Figure 8 Topics over time in sustainable tourism research (2005–2025). Source: Authors' work



industry. The plateauing trend indicates that, while green hotel practices remain strategically important, the research community is shifting its focus from establishing sustainability standards to evaluating their performance, impact, scalability, and integration with emerging technologies such as IoT-powered energy analytics and blockchain-based carbon monitoring systems. This transition from descriptive to performance-evaluative research represents a critical next step in translating sustainability principles into operational accountability frameworks for hospitality organisations.

5.1.3 Topics 2 (stakeholder engagement) and 3 (climate planning). Both themes demonstrate a steady, gradual rise, characteristic of long-term institutional evolution rather than an acute academic response to specific events. Research in these areas highlights the persistent challenge of coordinating multi-stakeholder governance systems, designing adaptive climate policy frameworks, and operationalising participatory planning processes within complex tourism ecosystems (Bramwell and Lane, 2011). Their gradual but consistent growth reflects the enduring relevance of governance-oriented research. It suggests that institutional inertia in tourism sustainability remains a productive area for policy-oriented inquiry, particularly as destinations increasingly require evidence-based governance tools to monitor and demonstrate progress on the SDGs.

5.1.4 Topic 4 (carbon emissions and energy management). Accelerating growth in this theme following 2022 coincides with intensifying global concern over carbon accountability, driven by international policy commitments such as COP26 and the European Union's Corporate Sustainability Reporting Directive (CSRD). Researchers have increasingly focused on methodologies for measuring carbon footprints, energy transition scenarios, and ESG reporting frameworks within tourism systems (Gössling and Peeters, 2015). This topic aligns directly with SDG 13 (Climate Action) and SDG 7 (Affordable and Clean Energy). Its growth trajectory reflects the mounting regulatory and reputational pressure on tourism enterprises to adopt standardised carbon accounting systems and transparent environmental performance reporting. This development positions carbon management as a core component of tourism performance management rather than a discretionary sustainability initiative.

5.1.5 Topics 5, 7, and 9 (indicators, planning, resilience). These themes experienced a visible decline after 2024, which may reflect saturation within the established literature on sustainability indicators, land-use models, and pandemic-induced risk frameworks. As comprehensive indicator sets and resilience frameworks have accumulated across the literature, academic interest is redirecting toward implementation, adoption, and performance evaluation phases (UNEP, 2021; Papageorgiou, 2025). The deceleration of pandemic-related risk modelling within Topic 9 further suggests that the field's focus is shifting from crisis response toward systemic

long-term recovery and adaptive resilience planning, with implications for how tourism organisations design and evaluate their risk management performance systems.

5.1.6 Topic 8 (COVID-19 and crisis tourism). The sharp spike in 2020, followed by rapid dissipation, reflects the concentrated nature of pandemic-driven academic production. Studies published during 2020 and 2021 predominantly examined crisis management strategies, destination vulnerability assessments, and the short-term economic impacts of travel restrictions on tourism-dependent communities (Otundo Richard, 2024). As global tourism systems have progressively recovered, scholarly attention has shifted toward systemic resilience, long-term destination recovery performance, and the structural reforms required to make tourism more robust against future disruptions, a transition that aligns with the broader movement toward performance-based sustainability governance.

5.1.7 Stable themes (e.g. Topics 6, 11, 13, 15, etc.). Themes including smart tourism technologies, coastal and marine tourism, rural community development, and tourist willingness-to-pay have exhibited stable but low-volatility patterns, reflecting their role as contextually specific or methodologically specialised subfields. Their expansion tends to be geographically concentrated or embedded within broader interdisciplinary research agendas (Garrod and Gossling, 2007; Gretzel et al., 2015; FAO, 2020). These stable themes represent important niche domains within sustainable tourism's performance landscape, offering opportunities for targeted policy interventions, localised sustainability monitoring systems, and place-specific performance benchmarking frameworks that complement the sector-wide metrics emerging from higher-growth research streams.

5.2 Predicting future dynamics of topic prevalence

To anticipate the future trajectory of research themes in sustainable tourism, Facebook Prophet was employed as the forecasting framework, an open-source time-series tool well-suited for annual and irregular publication data due to its capacity to model trend change points, seasonal patterns, and long-term growth trajectories (Taylor and Letham, 2018). By applying Prophet to each topic's yearly frequency generated through BERTopic's `topics_over_time` function, projected research interests through 2030 were transformed, transforming the study's static topic modelling outputs into a forward-looking analytical tool for researchers, policymakers, and tourism institutions.

Prophet fits an additive model combining trend, seasonality, and error components (as described in Section 2.3) and additionally generates upper and lower confidence bounds (`yhat_upper` and `yhat_lower`) for each projected value.

This structure enables flexible merging, visualisation, and slicing by topic and year, making it perfect for longitudinal trend analysis and multi-topic comparisons (see Table 7). As calculated by the Prophet additive model, the `yhat` column contains the predicted value (i.e. the estimated number of documents for a given topic in a specific year). It combines both trend and seasonal components to provide the best estimate of future topic prevalence based on historical publication patterns (see Table 8). Topics with historically volatile frequency patterns, such as Topic 8 (COVID-19) and Topic 0 (Tourist Behaviour), exhibit wider confidence intervals, reflecting greater uncertainty in their future trajectories. In contrast, stable themes such as Topic 13 (Rural Agritourism) and Topic 17 (Ecotourism) produce narrower intervals, indicating more predictable and consistent publication patterns. This distinction between high-uncertainty growth topics and low-uncertainty stable topics has practical implications for research planning and funding allocation, as it identifies both emerging priority areas and reliable knowledge domains within sustainable tourism.

Separate Prophet models were trained for each topic using historical annual publication counts as the baseline, with forecasts exported in structured CSV format for visualisation and policy

Table 7 Table head of predicted forecasting value

Topic	Year	yhat
0	2022	31.85285
0	2023	35.91108
0	2024	40.40241
0	2025	39.51894
0	2026	43.14255
0	2027	47.20078
0	2028	51.69211
0	2029	50.80863
0	2030	54.43225

Source(s): Authors' work

analysis. While Prophet provides interpretable trend and seasonality components, making it well-suited for academic planning and strategic foresight, it may be outperformed by hybrid or deep learning approaches in contexts involving nonlinear disruptions or structural breaks (Menculini *et al.*, 2021). The model's additive structure and changepoint detection capabilities nonetheless make it a robust and transparent tool for the evidence-based horizon scanning conducted in this study.

The Prophet-based forecasts reveal four distinct trajectory clusters that carry significant implications for the future direction of sustainable tourism research and its alignment with SDG-oriented sustainability governance objectives (see Figure 9).

5.2.1 Sharp growth cluster, Topics 0 and 1. Tourist Behaviour and Intention (Topic 0) and Green Hotel Practices (Topic 1) are forecast to expand substantially through 2030, with closely parallel growth trajectories indicating continued and mutually reinforcing research interest in demand-side behavioural sustainability and supply-side operational greening. This dual growth reflects the convergence of consumer-facing sustainability expectations and organisational performance imperatives within the post-pandemic tourism economy. The forecast momentum of these two topics is consistent with escalating demand for behavioural change measures, eco-certification uptake, and AI-driven personalisation strategies that align tourist preferences with sustainable destination offerings (Ajzen, 1991; Gretzel *et al.*, 2015; Gössling and Peeters, 2015). From a performance management perspective, the sustained growth of these themes signals that Key Performance Indicators anchored to tourist behaviour, including eco-friendly booking rates, sustainability satisfaction scores, and carbon-conscious destination choice indices, will increasingly become standard components of tourism performance reporting systems aligned with SDG 12 and SDG 13.

5.2.2 Gradual growth cluster, Topics 4 and 6. Carbon Emissions and Energy Management (Topic 4) shows a consistent, accelerating upward trajectory, projected to surpass Topics 2 and 3 in forecasted frequency by 2028. This growth is most likely driven by intensifying regulatory pressure from ESG disclosure mandates, carbon pricing mechanisms, and the sector-wide push toward net-zero tourism systems (Becken and Hay, 2007; Gössling and Peeters, 2015). Smart Tourism Technologies (Topic 6) exhibits moderate but steady growth, reflecting its developing role as a complementary sustainability enabler rather than a standalone research priority. The gradual slope of Topic 6 suggests that the research community is still working to establish robust empirical frameworks for evaluating the sustainability impact of digital tourism systems, and that interdisciplinary collaboration between technology researchers and sustainability governance scholars will be essential for accelerating this trajectory. Both topics align with SDG 9 (Industry, Innovation and Infrastructure) and SDG 13, and their combined growth signals the emergence of a technology-enabled carbon accountability paradigm within tourism performance management.

Table 8 Forecasted topic growth trends (2025–2030)

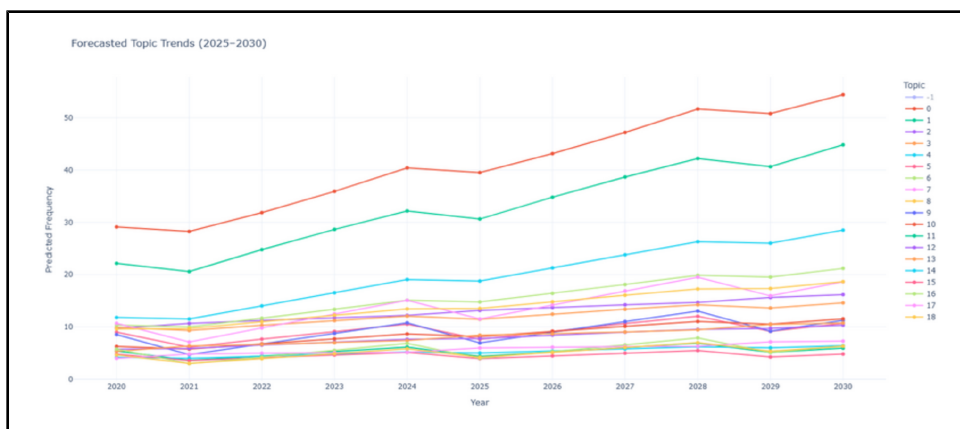
Topic	Topic name	Forecast trend	Interpretation
0	Tourist Behaviour and Travel Intention	Sharp Growth	Rising sharply, likely driven by AI, personalisation, and sustainability nudging
1	Green Practices in the Hotel Industry	Sharp Growth	Tracking Topic 0 closely, operational greening remains highly relevant
2	Stakeholder Engagement in Sustainable Tourism	Slight Growth	Minimal increase is still relevant, but it is losing novelty
3	Climate-Oriented Sustainable Tourism Development	Flat	The forecast is a stagnant strategic climate discourse plateauing in tourism research
4	Carbon Emissions and Energy Management	Gradual Growth	Stable rise driven by global carbon policy and decarbonisation pressure
5	Sustainability Indicators and Policy Frameworks	Gradual Decline	Unstable, declining older frameworks are being replaced or seen as saturated
6	Smart Tourism Technologies and Research Trends	Gradual Growth	The slow, steady climb reflects increased tech integration
7	Ecological Coordination and Spatial Planning	Gradual Decline	The forecast shows a fading academic interest in spatial sustainability planning
8	Impact of COVID-19 on Tourism Systems	Flat	It peaked in 2020 and is expected to fade completely by 2026
9	Disaster Resilience and Risk Management in Tourism	Gradual Decline	Steady declined, and crisis management lost focus post-COVID
10	Cultural Heritage and Urban Tourism	Stable	Niche and consistency: There is not much change in the forecasted volume
11	Coastal and Marine Tourism Activities	Stable	Flat projection, steady but low attention, may lack momentum for innovation
12	Circular Economy in Water and Waste Management	Stable/Slight Growth	Slow growth is emerging as an auxiliary sustainability theme
13	Rural and Community-Based Agritourism	Stable	Stable interest, often localised in development studies
14	Sustainability Education in Tourism	Stable	Forecast remains constant, limited to pedagogy-related works
15	Tourist Willingness to Pay and Destination Choice	Stable	Related to Topic 0, no distinct momentum independently
16	National Parks and Protected Area Tourism	Sharp Decline	Clear drop, possibly due to fewer fresh angles or low-tech integration
17	Ecotourism and Geotourism for Conservation	Stable	Niche theme, consistent but without significant forecasted growth
18	Tourism Modelling and Fuzzy Decision Approaches	Slight Growth	Method-focused potential rebound via innovative decision support systems

Source(s): Authors' work

5.2.3 Declining cluster, Topics 5, 7, 9, and 16. Sustainability Indicators and Policy Frameworks (Topic 5), Ecological Coordination (Topic 7), Disaster Resilience (Topic 9), and National Parks and Protected Area Tourism (Topic 16) all demonstrate declining or stagnating trajectories through 2030. These declines are most plausibly attributed to conceptual saturation within established frameworks, reduced urgency surrounding post-pandemic risk modelling, and a broader academic shift from framework development toward implementation, evaluation, and adaptive system design (Bramwell and Lane, 2011; Becken and Hughey, 2013). Rather than interpreting these declines as signals of diminishing importance, they may more accurately reflect the maturation of these domains, suggesting that future research should focus on empirically testing existing frameworks, evaluating implementation outcomes, and integrating established governance and planning models into broader performance management architectures spanning multiple SDG dimensions.

5.2.4 Stable cluster, Topics 8, 10, 11, 12, 13, 14, 15, 17, and 18. The remaining topics exhibit flat, low-variance trajectories, reflecting their positioning as contextually specific, methodologically

Figure 9 Forecasted topic trends in sustainable tourism research (2025–2030). Source: Authors' work



niche, or geographically concentrated subfields within the broader sustainable tourism research landscape. Topics including Cultural Heritage (10), Marine Tourism (11), Circular Economy Practices (12), Rural Agritourism (13), Sustainability Education (14), and Ecotourism (17) demonstrate consistent but modest publication volumes, indicating sustained scholarly interest without significant momentum for near-term growth. These stable themes nonetheless represent important dimensions of sustainable tourism's SDG performance landscape, particularly for destination-level and community-based sustainability monitoring. Their stability suggests that growth within these domains may depend on cross-thematic integration, connecting place-based sustainability research with emerging digital infrastructure, behavioural analytics, and governance innovation streams to generate new empirical insights and practical management tools.

The forecasting analysis collectively highlights a tightening convergence within sustainable tourism scholarship around three core performance management imperatives: behavioural change measurement, operational decarbonisation, and technology-enabled sustainability monitoring. These imperatives correspond directly to the SDGs most prominently represented across the study's thematic clusters, SDG 12, SDG 13, and SDG 9, and reflect both the internal logic of the research field's evolution and the external pressures of global sustainability governance frameworks. Themes grounded in reactive crisis management, static ecological planning and traditional indicator-based assessment are progressively being displaced by more dynamic, quantifiable, and accountability-oriented research paradigms. This transition carries significant implications for how tourism organisations, destinations, and policymakers design and evaluate their sustainability performance systems in alignment with the 2030 Agenda for Sustainable Development.

5.3 Future research directions

Informed by the thematic clustering, temporal trend analysis, and Prophet-based forecasting results, this study proposes that future research pursue integrative approaches bridging governance innovation, technological capability, and place-based tourism sustainability. This direction aims to foster more comprehensive and interdisciplinary frameworks that connect behavioural insights, operational accountability, and policy design within a cohesive, measurable research agenda aligned with the SDGs. Table 9 outlines key thematic areas identified as having significant potential for further exploration, based on emerging growth trajectories, underexplored research intersections, and forecasted shifts in scholarly attention through 2030.

Table 9 Future research directions

<i>Avenues</i>	<i>Future research directions</i>	<i>References</i>
Behavioural Change and Research	1. How can emerging insights from sustainability psychology be applied to close the gap between pro-environmental values and actual consumer behaviour in tourism? 2. How can digital nudging techniques be ethically and effectively integrated into AI-driven platforms to support a long-term, sustainable decision-making process? 3. How can AI-powered recommendation systems, behavioural data mining, and personalisation software be integrated with sustainability rewards to encourage travellers to choose low-impact travel options?	Gretzel (2011) , White et al. (2019)
Sustainability-Oriented Technological Innovation	How can emerging technologies such as blockchain-based supply tracking and IoT-based resource optimisation be integrated into smart tourism to enhance sustainability in tourism operations?	Koo et al. (2017)
Regenerative and Inclusive Tourism Models	How can the principles of regenerative tourism be implemented to move beyond the limitations of classic ecotourism and actively restore ecosystems and support local communities through travel? How can responsive development, community-capital building, and multi-stakeholder co-creation be effectively applied to empower disadvantaged areas through sustainable tourism initiatives?	Bellato et al. (2023) , Buzinde and Caterina-Knorr (2023)
Resilience and Adaptive Governance	How can new models of tourism resilience incorporate real-time risk tracking, mobility trend analysis, and dynamic crisis management systems to better prepare for future disruptions? How can adaptive governance structures be designed to incorporate real-time risk tracking, mobility trend analysis, and dynamic crisis management in response to growing socio-environmental complexity?	Prideaux and Beirman (2024)
Temporal and Predictive Sustainability Modelling	How can future studies compare Prophet with other forecasting methods, such as ARIMA and LSTM, while incorporating confidence calibration and dynamic SDG-tracking dashboards to support evidence-based policymaking for sustainable development?	Menculini et al. (2021)
Intersectional and Contextual Case-Based Analysis	How can a mixed-methods approach, such as spatial mapping, ethnography, and participatory tools, be used to uncover latent narratives in stable but low-growth tourism contexts and inform more inclusive and locally relevant tourism planning?	Truong et al. (2014)
Policy and Investment Alignment	How can academic research in tourism be better aligned with funding flows, national sustainability plans, and international standards such as GSTC, UNWTO sustainability indicators, and ESG metrics to close the research-policy-action loop?	Spenceley (2021) , UNWTO (World Tourism Organization) (2022)
Source(s): Authors' work		

6. Discussion

6.1 Key insights from topic evolution

The findings of this study reveal that sustainable tourism research has evolved from a primarily conservation-oriented discourse to a more integrated, performance-driven sustainability paradigm. Earlier tourism sustainability studies largely emphasised ecological preservation, destination protection, and community-based development. However, the temporal evolution identified through BERTopic modelling demonstrates a visible transition toward behavioural interventions, operational sustainability, carbon accountability, and technology-enabled tourism systems. This shift reflects broader global sustainability imperatives and signals an emerging alignment between academic research priorities, and the performance management demands of the tourism industry.

One of the most prominent developments is the increasing scholarly attention toward tourist behaviour and travel intention. The rapid growth of this topic reflects the growing importance of behavioural sustainability in tourism research, particularly in relation to environmentally responsible consumption patterns, eco-conscious destination selection, and digital personalisation strategies. This trend aligns closely with sustainability psychology frameworks such as the Theory of Planned Behaviour and Value-Belief-Norm Theory, which emphasise the role of individual attitudes and behavioural intentions in sustainable decision-making (Ajzen, 1991; Stern *et al.*, 1999). The increasing emphasis on behavioural change also reflects broader global sustainability priorities linked to SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action), suggesting that researchers are increasingly positioning individual tourist decisions as measurable leverage points within larger sustainability performance systems.

Similarly, the continued expansion of research on green hotel practices and carbon emissions management indicates that operational sustainability has become central to tourism research and industry transformation. Studies increasingly focus on energy efficiency, waste reduction, eco-certification systems, carbon accounting, and the integration of renewable energy within hospitality operations (Gretzel *et al.*, 2015; Gössling and Peeters, 2015). This shift demonstrates how sustainability is no longer viewed solely as an ethical concern but also as a strategic and performance-oriented requirement for tourism organisations. The growing institutionalisation of green practices within hospitality management indicates that sustainability performance metrics are increasingly embedded in operational decision-making, audit systems, and competitive benchmarking frameworks.

The forecasting analysis further suggests that future research will increasingly focus on climate accountability, technological integration, and measurable sustainability outcomes. Topics related to smart tourism technologies, AI-enabled decision systems, and sustainability analytics are demonstrating stable, long-term growth, reflecting the sector's transition toward data-driven tourism management. In contrast, themes such as ecological coordination, resilience planning, and traditional sustainability indicators show signs of stagnation or decline, potentially indicating conceptual maturity within these domains or a broader academic transition toward more adaptive, technology-oriented sustainability approaches. This trajectory implies that performance management in sustainable tourism will increasingly depend on real-time monitoring systems, predictive analytics, and digitally integrated accountability frameworks rather than static indicator-based assessments.

Another important insight emerging from the inter-topic semantic analysis is the growing interconnectedness between behavioural sustainability, governance systems, operational management, and technological innovation. The clustering of stakeholder engagement, policy frameworks, smart tourism, and resilience-oriented themes suggests that sustainable tourism is increasingly being conceptualised as an integrated socio-technical system rather than an isolated environmental initiative. This evolution reflects the growing recognition that achieving the Sustainable Development Goals requires coordinated action across behavioural, institutional,

technological, and operational dimensions, with significant implications for how tourism organisations design, monitor, and report on their sustainability performance.

6.2 Gaps in current research

Despite the growing sophistication of sustainable tourism research, several conceptual and practical gaps remain evident within the existing literature. One of the most significant gaps is the imbalance between behavioural sustainability research and structural or policy-oriented transformation. A substantial proportion of recent studies emphasise individual behavioural interventions, eco-conscious decision-making, and willingness-to-pay models. At the same time, comparatively less attention is devoted to systemic governance reform, regulatory enforcement mechanisms, and institutional accountability structures. This creates a research landscape that heavily prioritises consumer responsibility while underemphasising the structural conditions that enable or constrain tourism sustainability outcomes at the organisational and destination levels.

A related and equally significant gap concerns the limited translation of SDG-oriented tourism research into operational, measurable frameworks. Although many studies conceptually align tourism themes with the Sustainable Development Goals, relatively few provide concrete performance indicators, implementation models, or measurable sustainability benchmarks for tourism organisations and destinations. This disconnect between academic sustainability discourse, and practical performance management constitutes a critical barrier to operationalising the 2030 Agenda in the tourism sector. Future research must therefore move beyond conceptual SDG mapping to develop applied performance frameworks that translate sustainability principles into actionable metrics, reporting standards, and organisational accountability systems.

The findings also reveal limited integration between technological innovation and sustainability governance. While smart tourism technologies and AI-based systems are increasingly discussed in isolation, fewer studies examine how digital infrastructures can be embedded into long-term sustainability governance, destination resilience planning, or regulatory compliance systems. This disconnect limits the practical applicability of technological sustainability research and reduces its capacity to inform evidence-based policy and management decisions. Bridging the gap between technological capability and governance integration represents one of the most consequential research opportunities within the sustainable tourism literature.

Additionally, several research themes remain geographically and contextually concentrated. Topics such as rural agritourism, marine tourism, and protected-area tourism often rely on localised case studies with limited scalability or cross-regional comparability. This geographical concentration creates challenges in developing universally adaptable sustainability frameworks across diverse tourism ecosystems, particularly in developing country contexts where tourism's contribution to SDG achievement is most consequential. Greater investment in comparative, multi-regional, and longitudinal research designs would substantially strengthen the generalisability and policy relevance of findings across these thematic areas.

The forecasting analysis further suggests that some sustainability domains may be approaching conceptual saturation. Topics related to sustainability indicators, ecological zoning, and crisis resilience show declining academic momentum, potentially signalling a repetition of existing frameworks rather than the development of innovative sustainability models. Future research should move beyond descriptive sustainability assessments toward predictive, adaptive, and intervention-oriented research designs that generate new theoretical and empirical contributions rather than consolidating established ones.

Finally, the study highlights the limited use of longitudinal and predictive modelling approaches within sustainable tourism research. Although topic modelling and forecasting techniques offer

substantial potential for identifying emerging sustainability trajectories, these methods remain underutilised in tourism scholarship. Greater integration of machine learning, forecasting analytics, and dynamic SDG monitoring systems could significantly strengthen the evidence base for tourism planning, sustainability governance, and policy evaluation, offering a more forward-looking and performance-oriented research paradigm for the field.

6.3 Super-topic synthesis and SDG convergence

The inter-topic distance-mapping and hierarchical clustering results reveal that the 18 identified research themes can be meaningfully organised into four super-topics: Consumer Behaviour Core, Cultural and Place-Based Convergence, Policy and Governance, and Environmental Operations. This super-topic structure is not merely a descriptive taxonomy; it represents the underlying architecture through which sustainable tourism research collectively engages with the Sustainable Development Goals (UN, 2015) and, by extension, with the performance management challenges facing the tourism sector.

The Consumer Behaviour Core, comprising research on tourist behaviour, travel intention, and willingness-to-pay, converges most strongly around SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). This cluster reflects the growing recognition that individual tourist decisions constitute a primary lever for sustainable tourism performance. Research within this super-topic increasingly informs demand-side performance management strategies, including eco-labelling systems, digital nudging mechanisms, and behavioural analytics platforms that enable tourism organisations and destinations to monitor and influence sustainable consumption patterns at scale.

The Cultural and Place-Based Convergence super-topic, encompassing cultural heritage, national parks, ecotourism, and rural agritourism, aligns predominantly with SDG 11 (Sustainable Cities and Communities) and SDG 15 (Life on Land). While these themes have demonstrated stable but low-growth trajectories in the forecasting analysis, they represent a foundational dimension of sustainable tourism performance that is often underrepresented in quantitative performance frameworks. The cultural and ecological integrity of tourism destinations constitutes a long-term performance asset that requires dedicated monitoring, conservation investment metrics, and community participation indicators, dimensions that current performance management systems frequently overlook.

The Policy and Governance super-topic, which consolidates stakeholder engagement, sustainability indicators, smart tourism, COVID-19 impacts, disaster resilience, and tourism modelling themes, engages most directly with SDG 17 (Partnerships for the Goals), SDG 11, and SDG 13. This cluster reflects the institutional and regulatory architecture that governs tourism sustainability management and measurement. The forecasting analysis indicates that governance-oriented research is approaching a period of consolidation, suggesting that the field may be transitioning from framework development toward implementation and evaluation, a shift with important implications for performance management, as it signals growing demand for applied governance tools, cross-sectoral accountability mechanisms, and evidence-based policy evaluation systems.

The Environmental Operations super-topic, encompassing green hotel practices, carbon emissions management, coastal and marine tourism, and circular economy practices, aligns most directly with SDG 12, SDG 13, and SDG 7 (Affordable and Clean Energy). This cluster represents the operational core of sustainable tourism performance management, where sustainability principles are most directly translated into measurable organisational outcomes. The continued growth of carbon emissions and energy management research within this super-topic reflects the intensifying pressure on tourism enterprises to adopt standardised environmental reporting systems, carbon accounting frameworks, and ESG-aligned performance indicators, developments that position operational sustainability as both a regulatory compliance requirement and a strategic competitive differentiator.

Taken together, these four super-topics illustrate that sustainable tourism research does not engage with the SDGs in isolation but rather through an interconnected system of behavioural, cultural, institutional, and operational dimensions. A comprehensive approach to performance management in sustainable tourism must therefore span all four super-topics, integrating demand-side behavioural monitoring, supply-side operational accountability, governance system evaluation, and place-based cultural and ecological stewardship within a unified and measurable performance framework. This integrated perspective represents the study's most significant practical implication. It provides a structural basis for future research, policy design, and organisational strategy within the global sustainable tourism sector.

7. Implications

7.1 Managerial implications

The thematic clusters and forecasting trajectories identified in this study carry direct and substantive implications for performance management within tourism organisations, hospitality operations, and destination governance systems. The temporal evolution of sustainable tourism research demonstrates a growing institutional demand for measurable sustainability indicators that can translate academic sustainability principles into operational decision-making frameworks, a transition that positions performance management as the critical bridge between scholarly insight and real-world sustainability outcomes.

The increasing prominence of green hotel practices, carbon emissions management, and sustainable tourist behaviour collectively signals that tourism organisations must move decisively beyond symbolic sustainability initiatives toward performance-based sustainability management systems. In this context, Key Performance Indicators (KPIs) serve not merely as monitoring tools but as strategic instruments for driving accountability, enabling benchmarking, and aligning organisational operations with SDG objectives at the destination and enterprise level (UN, 2015). The four super-topics identified through the inter-topic distance analysis, Consumer Behaviour Core, Cultural and Place-Based Convergence, Policy and Governance, and Environmental Operations, provide a structural basis for organising tourism performance management systems across behavioural, cultural, institutional, and operational dimensions simultaneously.

Table 10 presents a proposed framework linking major research themes with practical sustainability performance indicators, offering tourism organisations, destination management bodies, and policymakers a structured tool for translating the study's thematic findings into measurable management action.

The implementation of such indicators supports evidence-based decision-making across multiple tourism stakeholder groups. Hotel operators can utilise energy consumption, waste recycling, and carbon emission metrics to evaluate operational efficiency, guide investment in sustainable infrastructure, and demonstrate regulatory compliance under ESG disclosure frameworks such as the EU's Corporate Sustainability Reporting Directive (CSRD). Destination management organisations can deploy behavioural sustainability indicators, community participation indices, and digital engagement metrics to monitor tourist alignment with sustainable destination strategies and evaluate the effectiveness of eco-labelling and nudging interventions. Policymakers and national tourism authorities can apply carbon accounting and governance indicators to assess the systemic effectiveness of tourism sustainability policies, benchmark destination performance against international SDG targets, and allocate public investment toward the highest-impact sustainability interventions.

The forecasting analysis also suggests that digital monitoring infrastructures and predictive sustainability analytics will increasingly shape future tourism performance management systems. Smart tourism technologies, AI-driven recommendation systems, and IoT-enabled resource monitoring platforms have the potential to substantially enhance real-time sustainability tracking, predictive planning, and operational transparency across tourism ecosystems (Gretzel *et al.*,

Table 10 Research themes and performance management indicators for future tourism

<i>Research theme</i>	<i>Super-topic</i>	<i>Example KPI</i>	<i>SDG alignment</i>	<i>Practical application</i>
Green Practices in Hotels	Environmental Operations	Energy consumption per guest night	SDG 12, SDG 13	Operational sustainability benchmarking
Carbon Emissions Management	Environmental Operations	CO ₂ emissions per tourist per trip	SDG 13, SDG 7	Carbon accountability and ESG reporting
Tourist Behaviour and Intention	Consumer Behaviour Core	Percentage of eco-friendly bookings	SDG 12, SDG 13	Behavioural sustainability tracking
Circular Economy Practices	Environmental Operations	Waste recycling rate (%)	SDG 12, SDG 6	Resource efficiency monitoring
Smart Tourism Technologies	Policy and Governance	Digital sustainability engagement rate	SDG 9, SDG 11	Smart destination management
Stakeholder Engagement	Policy and Governance	Community participation index	SDG 17, SDG 11	Governance and inclusivity assessment
Rural and Community Tourism	Cultural and Place-Based	Local employment generation rate	SDG 8, SDG 11	Socio-economic sustainability evaluation
Cultural Heritage Tourism	Cultural and Place-Based	Heritage conservation investment ratio	SDG 11, SDG 4	Cultural sustainability management
Sustainability Education	Policy and Governance	Staff sustainability training hours	SDG 4, SDG 12	Capacity building and awareness monitoring

2015). The integration of these technologies into performance management systems represents one of the most consequential strategic opportunities for tourism organisations seeking to embed sustainability as a core operational competency rather than a peripheral reporting obligation.

Furthermore, the transition toward measurable sustainability performance reflects a broader institutional shift from sustainability as a conceptual aspiration toward sustainability as a strategic management function. This transformation is particularly important for achieving SDG 12, SDG 13, and SDG 11, which require not only stated commitments but demonstrable, monitored, and publicly reported progress, a standard that only robust performance management systems, grounded in credible and comparable indicators, can reliably meet.

7.2 Policy and strategic implications

The study's findings carry significant implications for policymakers, tourism authorities, destination management organisations, and hospitality enterprises seeking to align strategic operations with global sustainability governance frameworks. The projected growth of research themes related to behavioural sustainability, carbon management, and operational greening signals that future tourism policy will increasingly require measurable accountability mechanisms, standardised reporting systems, and cross-sectoral governance structures rather than purely aspirational sustainability narratives.

7.2.1 Policymakers. For national and regional policymakers, the findings highlight the urgent need to strengthen sustainability governance frameworks through standardised environmental reporting systems, mandatory carbon disclosure mechanisms, and destination-level sustainability benchmarking programs. Tourism sustainability policies would benefit significantly from integrating ESG-oriented performance frameworks, carbon accounting systems aligned with international reporting standards, and digital sustainability monitoring infrastructure that enables transparent, comparable assessment of SDG progress across destinations and market segments. The declining trajectory of traditional sustainability indicator research further suggests that policy frameworks built around static indicator sets may be approaching obsolescence, and that future governance systems will require more dynamic, real-time, and adaptive monitoring architectures.

7.2.2 Hotel operators. For hospitality organisations and tourism enterprises, the increasing emphasis on operational sustainability signals that environmental performance will become a primary competitive and reputational differentiator within the global tourism industry. Hotels, tour operators, and travel intermediaries must therefore integrate sustainability metrics directly into strategic planning cycles, operational auditing processes, and service management systems. Practices including energy optimisation through smart building technologies, waste minimisation through circular economy principles, adoption of eco-certification, and AI-assisted resource monitoring are transitioning from voluntary sustainability gestures to essential components of long-term organisational competitiveness and regulatory compliance. The forecasting results specifically indicate that carbon emissions management and green operational practices will attract intensifying academic and regulatory scrutiny through 2030, making early adoption of robust carbon accounting and ESG reporting systems a strategic priority for tourism enterprises of all scales.

7.2.3 Destination management organisations (DMOs). For destination management organisations, the super-topic analysis highlights the importance of developing integrated destination sustainability strategies that simultaneously address behavioural, operational, governance, and place-based sustainability dimensions. Destinations that invest in behavioural sustainability monitoring systems, tracking eco-friendly tourist decision-making, willingness-to-pay for sustainable experiences, and carbon-conscious transport choices, alongside operational sustainability auditing and community participation governance frameworks, will be better positioned to demonstrate credible SDG alignment, attract sustainability-conscious market segments, and access international climate finance and green investment flows increasingly directed toward demonstrably sustainable tourism destinations.

The findings also emphasise the strategic importance of balancing technological innovation with social inclusion and community participation within destination sustainability strategies. While smart tourism technologies offer significant opportunities for sustainability monitoring and operational optimisation, equitable and resilient sustainable tourism development must simultaneously preserve cultural identity, support local livelihoods, and ensure meaningful participatory governance processes. This balance is particularly critical for rural, heritage, and ecotourism destinations, where sustainability outcomes are most directly linked to community engagement, cultural stewardship, and ecosystem integrity, dimensions that quantitative performance frameworks must be designed to capture alongside environmental and economic indicators.

7.3 Research implications

The methodological and thematic contributions of this study open several important avenues for future scholarly inquiry within sustainable tourism research. The application of BERTopic modelling combined with Prophet-based forecasting demonstrates that computational text analysis and time-series prediction can be productively integrated to generate both retrospective thematic maps and prospective research trajectory forecasts, a methodological combination that remains largely underexplored within tourism scholarship and offers substantial potential for replication, extension, and refinement across adjacent fields.

Future researchers are encouraged to extend the forecasting framework employed in this study by incorporating alternative predictive models alongside Prophet, including ARIMA, LSTM, and hybrid BiLSTM-Transformer architectures, to enable comparative assessment of forecasting accuracy and model sensitivity across different temporal patterns of academic production (Menculini *et al.*, 2021; Yi *et al.*, 2021). The integration of confidence interval visualisation and dynamic SDG tracking dashboards within such forecasting systems could further enhance their utility as evidence-based policy planning tools, enabling real-time monitoring of research alignment with evolving global sustainability priorities.

The super-topic structure identified in this study, Consumer Behaviour Core, Cultural and Place-Based Convergence, Policy and Governance, and Environmental Operations, also provides a theoretically grounded framework for organising future sustainable tourism research agendas. Researchers are encouraged to pursue cross-subject investigations that examine the interactions between behavioural sustainability, governance innovation, technological infrastructure, and place-based ecological stewardship, as these intersections represent the most underexplored and potentially high-impact areas within the current research landscape. Interdisciplinary collaborations spanning tourism management, environmental science, data science, behavioural economics, and public policy will be essential for building the integrated knowledge base needed to advance sustainable tourism as a measurable, accountable instrument for achieving the SDGs.

Finally, the study highlights the methodological value of incorporating multilingual corpora, non-Scopus and non-Web of Science indexed literature, and grey literature sources, including policy reports, industry sustainability disclosures, and NGO publications, into future bibliometric and computational analyses of sustainable tourism research. Broadening the evidence base in this manner would substantially improve the geographic representativeness, disciplinary diversity, and policy relevance of future thematic mapping and forecasting studies, ensuring that the research community's understanding of sustainable tourism's intellectual landscape more accurately reflects the full breadth of global scholarly and practitioner contributions to the field.

8. Conclusion

This study presents a comprehensive bibliometric and computational analysis of sustainable tourism research spanning 2005 to 2025. By integrating BERTopic modelling with Prophet-based forecasting, it uncovers the structural architecture of sustainable tourism scholarship. It projects its future evolution through 2030, providing an evidence-based foundation for research planning, policy design, and sustainability governance within the global tourism sector.

Addressing [RQ1](#), the findings reveal a clear transition from conservation-oriented, descriptive sustainability discourse toward a performance-driven, accountability-focused research paradigm. Research themes linked to SDG 12 and SDG 13 experienced the most sustained growth. In contrast, governance and resilience-oriented themes reached consolidation, reflecting the growing academic recognition that sustainable tourism must be operationalised through measurable systems rather than aspirational narratives.

Addressing [RQ2](#), BERTopic identified 18 thematic clusters organised into four super-topics: Consumer Behaviour Core, Cultural and Place-Based Convergence, Policy and Governance, and Environmental Operations. Six SDGs emerged as most prominently represented: SDG 8, SDG 11, SDG 12, SDG 13, SDG 15, and SDG 17. This multidimensional structure confirms that SDG engagement in sustainable tourism spans behavioural, institutional, operational, and place-based dimensions simultaneously.

Addressing [RQ3](#), Prophet-based forecasting identified four trajectory clusters through 2030. Tourist behaviour and green hotel practices are forecast to grow sharply. Carbon emissions management and smart tourism technologies are showing gradual yet consistent growth, while sustainability indicators, ecological planning, and disaster resilience are showing declining trajectories. Cultural heritage, marine, and rural tourism themes remain stable but contextually significant.

The study's novel pipeline, combining transformer embeddings, UMAP, HDBSCAN, c-TF-IDF, GPT-4 labelling, SDG mapping, and Prophet forecasting, transforms conventional bibliometric review into a predictive, decision-support instrument for tourism scholarship and governance.

Several limitations warrant acknowledgement. The corpus is restricted to English-language publications from Scopus and Web of Science, which may introduce bias in the index. Manual SDG mapping carries inherent interpretive subjectivity. Prophet's additive structure may not fully

capture non-linear disruptions from policy shocks or geopolitical events (Liu *et al.*, 2023). Future studies should incorporate multilingual corpora, automated SDG classifiers, and hybrid forecasting models combining Prophet with LSTM or Transformer-based architectures.

In summary, this study maps the intellectual landscape of sustainable tourism research, assesses its alignment with the SDGs, and projects its future trajectory using a novel computational methodology, equipping researchers, practitioners, and policymakers with the foresight required to advance sustainable tourism as a measurable instrument of global development in the decade ahead.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article.

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