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From moon landing to metaverse: Tracing the evolution of *Technological Forecasting and Social Change*

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ABSTRACT

Technological Forecasting and Social Change (*TFSC*) is one of the most prominent journals to focus on the methodologies and practices of technological forecasting and futures studies. This study aims to analyse the topical structure of *TFSC* and track the most cited articles published in the journal using a combination of a structural topic model (STM) and bibliometric analysis. The STM reveals 18 prominent topics in *TFSC*, and the topical quality of the STM results is verified based on semantic coherence and topic exclusivity scores as well as an assessment of the correlations among topics. The STM also tracks the temporal variations in topical prevalence that occurred from 1969 to 2022, shedding light on the changing popularity of each topic. The bibliometric analysis presents a decade-by-decade perspective on the most cited articles and the geographical dispersion of authors affiliated with *TFSC*, thereby providing a truly global perspective on the journal's publishing activity.

1. Introduction

Technological Forecasting and Social Change (*TFSC*) is a leading international journal that is dedicated to publishing novel and rigorous research on the methodology and practice of technological forecasting and futures studies by reference to environmental, social, and technological factors. The year 1969 is significant in the history of mankind since it was during this year that humans landed on the moon for the first time, which was a landmark technological breakthrough. This development served as the impetus for the launch of *TFSC* in 1969 under the title of *Technological Forecasting*; the journal was rebranded as *Technological Forecasting and Social Change* in the mid-1970s. The inaugural editor-in-chief of the journal was Harold A. Linstone, and the current editors-in-chief are Scott Cunningham and Mei-Chih Hu.

In addition to *TFSC*, the major journals that publish research on *forecasting* (i.e., conventional—*predicting the most likely future*) and *futures studies* (i.e., contemporary—*dealing with multiple future scenarios*) include *Foresight*, *Futures*, *Futures and Foresight Science*, *International Journal of Forecasting*, *Journal of Forecasting*, *Journal of Futures Studies*, and *Long Range Planning*, among others. However, unlike these journals, *TFSC* recognizes the central role of technology in this context and thus includes technology as a key focus in its methodologies and practices for forecasting and future studies. The growing reputation of *TFSC* is evidenced by various citation- and peer review-based measures. According to Clarivate Analytics, *TFSC*'s impact factor is 10.884, indicating that the average number of citations of articles published in *TFSC* in 2020 and 2021 was 10.884 in 2021. Furthermore, according to Scopus, *TFSC*'s 2021 CiteScore is 13.7, signifying that articles published in the journal between 2018 and 2021 received an average of 13.7 citations in 2021, while its source normalized impact per paper (SNIP) is 3.099, indicating

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that articles published in *TFSC* receive 3.099 times the average citations received by articles published in other journals in the field, in which context "field" refers to the collection of documents citing the journal. When subject areas are considered, *TFSC* is ranked 12 out of 423 under 'Business, Management and Accounting: Business and International Management', nine out of 279 under 'Business, Management and Accounting: Management of Technology and Innovation', and eight out of 230 in 'Psychology: Applied Psychology' as per Scopus's CiteScore for 2021. In addition to citation-based measures, *TFSC* receives a rating of "A" from the Australian Business Deans Council (ABDC) Journal Quality List (JQL) 2019 and a rating of "3" from the Chartered Association of Business Schools (CABS) Academic Journal Guide (AJG) 2021, thus indicating its status as a premier journal in the field.

Unlike the progressive stability of the past, the contemporary world faces significant economic, environmental, and social turbulence as well as rapid and ongoing technological advancement. Recent events such as the COVID-19 pandemic (Lim, 2021) and the Ukraine-Russia conflict (Lim et al., 2022a) have completely disrupted both business and society, intensifying uncertainty regarding the future. Such scenarios accentuate and reaffirm the necessity, importance, relevance, and urgency of technological forecasting and futures studies. Building on previous reviews of *TFSC*, which have taken a *nontemporal* approach to science mapping and thus offered insights based on a *static* perspective (Mas-Tur et al., 2021; Sarin et al., 2020; Singh et al., 2020a, 2020b), the present study aims to explore the *evolution* of *TFSC*'s topical structure and performance to generate new insights from a *dynamic* perspective regarding the period beginning with the moon landing in 1969 and concluding with the spectacle of the metaverse in 2022 (Kraus et al., 2022a). Therefore, this study endeavours to answer the following research questions (RQs):

RQ1. What are the most prominent topics in *TFSC*, and how have these topics evolved over time?

RQ2. What variations in topical prevalence in *TFSC* occur over time?

RQ3. What are the publication trends exhibited by *TFSC* over time?

RQ4. What are the most influential articles in *TFSC*, and how have they evolved over time?

RQ5. What is the geographical dispersion of the authors published in *TFSC*, and how has this dispersion evolved over time?

To answer these research questions, this study employs a hybrid methodology that combines a machine learning-based structural topic model (STM) and bibliometric analysis. The STM is used to discover the pattern of topics within the target body of text and to analyse how these topics have evolved. Based on the STM, this study identifies 18 major topics that characterize the topical structure of *TFSC*. Notably, this study not only identifies the major topics of the journal but also ensures the topical quality of the STM results using methods such as semantic coherence and topic exclusivity scores alongside an assessment of the correlations among topics. Furthermore, this study sheds light on the changing popularity of topics between 1969 and 2022 by scrutinizing the temporal variations in topical prevalence. Finally, this study provides a decade-by-decade analysis of the most cited articles in *TFSC* and analyses the geographical dispersion of authors affiliated with *TFSC* over time.

The remainder of this article is organized as follows. The second section describes the efforts made by *TFSC* to engage with contemporary issues. The third section discloses the methodology used in the study. The fourth section presents the results of the STM and bibliometric analysis of *TFSC*. The fifth section presents the conclusions and implications of the study, and the sixth section describes directions for future research.

2. *TFSC*'s engagement with contemporary issues

TFSC is a pioneer in the publication of research on topical issues that affect global economies. The journal focuses on issues that lie at the intersection of technology and society and have implications for the economy and the environment. One important strategy employed by the journal is to solicit and publish special issues (SIs) on trending issues in the discipline. The first SI was published a decade after the inception of the journal in 1979. These SIs are considered to represent an important instrument that can be used to strengthen the association between a journal and emerging areas of interest. According to the editorial by Phillips (2014), SIs gain more attention from readers, receive an above-average number of citations.

Table 1 shows the latest SIs published by *TFSC*. These SIs are curated based on trending topics, ranging from climate change, entrepreneurship, and sustainability to cutting-edge technologies involving artificial intelligence and big data. The SIs are based on contemporary issues that pertain to the interaction of technology with the social and environmental aspects of business management. The SIs offer authors the opportunity to publish their latest and most innovative research on the use of the latest technologies to solve pressing issues. The SIs also introduce unique behavioural themes, such as 'Psychological perspectives on technological innovations', 'Video game industry, users' gaming behaviours, and social policy', and 'Interactions between humans and social robots put to the test', among others. A study conducted by Ashraf et al. (2022) assessed the use of SIs by *TFSC*, showing that the journal has made good use of SIs to increase the academic visibility of trending issues and to find solutions to pressing issues, resulting in significantly higher citations for SIs than for regular issues (RIs). This fact highlights and reaffirms the value of SIs for TFSC.

3. Methodology

3.1. Structural topic model (STM)

This study uses a STM to identify, explore, and visualize key topics from extant research published in *TFSC*. STM is a probabilistic generative topic modelling technique that models each document in a textual corpus as a collection of topics and models each topic as a probabilistic mixture of terms (Roberts et al., 2014). Hence, STM can uncover the latent conceptual structure of a finite and discrete text dataset and map each text document as a weighted blend of key topics. The abstract, title, and keywords of each *TFSC* article published between 1969 and 2022 were combined to create a text dataset for the topic modelling process following the standard practice employed in previous works (Baker et al., 2021; Sharma et al., 2021). The STM represents each topic as a probabilistic collection of terms, in which context each topic can be summarized by the top n terms that are most frequently associated with the topic. The frequency and exclusivity (FREX) score is used to identify terms that are frequent in a topic but not frequent in other topics (Roberts et al., 2019). The terms most frequently associated with a topic can be used to provide a meaningful label for that topic (Baker et al., 2021).

3.1.1. Data and text preprocessing

Textual data related to copyright and publisher were removed from each article. As topic modelling uses a vector-space model based on the bag-of-words approach to the statistical analysis of text, it ignores the positional context of bigrams and trigrams, which may have scholarly significance. This study utilized a special procedure to preserve the semantic associations of cooccurring words in an n-gram term. The most frequent bigrams and trigrams were extracted from the textual corpus using an n-gram tokenizer included in R software. These bigrams and trigrams were concatenated to preserve their semantic meaning in the text. Hence, bigrams such as "technology roadmapping" were converted to "technologyroadmapping". Similarly, trigrams such as "business

Table 1
Recent special issues in *TFSC*.

No	Title of special issue	Guest editors	Year
	Climate change, technological innovation and social change: Socio-economic challenges and role of climate-tech	Muhammad Shahbaz, Andreas Kontoleon, Muhammad Ali Nasir, and Sudharshan Reddy Paramati	2022
	Artificial intelligence as an enabler for innovation	Yann Truong, Savvas Papagiannidis, and Dirk Schneckenberg	2022
	Low carbon energy transition, renewable energy technologies and energy poverty	Dalia Streimikiene, Malin Song, Zhiyang Shen, and Tomas Balezentis	2022
	Technological and social change in entrepreneurship: How big data can benefit society	Daniel Palacios-Marqués, Joaquin González-García, and Juan Piñeiro-Chousa	2022
	Social customer journey – Behavioural and social implications of digitally disruptive environment	Muhammad S. Akram, Yogesh K. Dwivedi, Mahmud A. Shareef, and Zeeshan A. Bhatti	2022
	Technological management and corporate social responsibility: Social change towards new forms of financing	William McDowell, C. José García, Carlos Lassala, and Samuel Ribeiro-Navarrete	2022
	The political economy of the climate crisis after the discussions in the COP 26 Summit	Scott Cunningham, Giray Gozgor, and Karoline Rogge	2022
	Technology as catalyst for sustainable social business: Advancing the research agenda	Chrysostomos Apostolidis, Riad Shams, Diana Gregory-Smith, Demetris Vrontis, Xuemei Bian, and Zhanna Belyaeva	2022
	Forecasting, entrepreneurial opportunities, and technology	Gary Castrogiovanni and Virginia Simón-Moya	2022
	Advanced tech mining: Technical emergence indicators and measurements	Yi Zhang, Alan Porter, and Huang Ying	2022
	Research methods in technology management, forecasting and social change	João J. Ferreira and Justin Paul	2022
	Low carbon energy transition, renewable energy technologies and energy poverty	Dalia Streimikiene, Malin Song, Zhiyang Shen, and Tomas Balezentis	2022
	Psychological perspectives on technological innovations	Michael Christofi, Elias Hadjielias, Olga Kvasova, Karena Yan, and Danae Manika	2022
	Video game industry, users' gaming behaviours, and social policy	Jang Hyun Kim and Hao Jiao	2022
	Winds of change: The evolving relationship of entrepreneurship, small businesses, technology, and innovation;	Eric Liguori, Fred Phillips, Xaver Neumeyer, Raj V. Mahto, Susana Santos, and Steven T. Walsh	2022
	Technologies and digital transformation for sustainability in agribusiness	Maria Carmela Annosi, Francesco Paolo Appio, Esteban R. Brenes, and Federica Brunetta	2022
	Sustainability-oriented innovation in agri-food systems: Technological change and beyond	Stefania Testa, Kristian Roed Nielsen, Steen Vallentin, and Federica Ciccullo	2022
	Heuristics in *TFSC*	Wolfgang Guettel	2022
	Opening up the black box on digitalization and agility: Key drivers and main outcomes	Stefano Bresciani, Alberto Ferraris, Gabriele Santoro, and Masaaki Kotabe	2022
	Technological innovations to ensure confidence in the digital world	Jean-Michel Sahut, Denis Schweizer, and Marta Peris-Ortiz	2022
	Using complexity theory to build accurate and generalizable models of technological forecasting and social change	Kun-Huang Huarng and Alessandro Zardini	2022
	Interactions between humans and social robots put to the test	Steffen Kinkel, Bettina-Johanna Krings, and Kerstin Cuhls	2022
	Management engineering and innovative management, information and production for social change	Bing Xu, Juying Zeng, Francisco Vidal, and Jose Ramon Saura	2022
	Management of joint university-industry laboratories	Dirk Meissner, Yuan Zhou, Bruno Fischer, and Nicholas Vonortas	2022
	Industry 4.0: The role of social, environmental and technological factors for the development of digital manufacturing	Sachin Kumar Mangla, Sunil Luthra, Jose Arturo Garza-Reyes, Charbel Jose Chiappetta Jabbour, and Alexander Brem	2022
	Technology and religion: Emerging paradigms of social change	Léo-Paul Dana and Shangfeng Zhang	2022
	Technology and social change during the pandemic crisis	Sang M. Lee, Arben Asllani, and M. Angelese Lopez-Cabarcos	2022
	Digitalization adding value to healthcare	Yichuan Wang, William Yu Chung Wang, Minhao Zhang, Danae Manika, and Savvas Papagiannidis	2022
	Innovation, management, and governance for sustainable growth	Agustín Carrilero Castillo, Dolores Botella Carrubi, and Helena Mogorrón	2022
	Data intelligence and analytics: Understanding the capabilities and potential benefits for business and societal transformation	Jonathan Calof, Tugrul Daim, and Mourad Oubrich	2022
	Big data and network analysis in national innovation systems	Vania Sena, Nieves Arranz, Pablo Lucas, Han Woo Park, and Juan Carlos Fernandez de Arroyabe	2022
	Innovation, entrepreneurship and knowledge	María Guijarro García, José Manuel Guaita, and Carla Martínez Climent	2022
	From latent to emergent entrepreneurship	David Audretsch, Rosa Caiazza, Maksim Belitski, Christina Guenther, and Matthias Menter	2022
	Technological innovations to ensure confidence in the digital world	Jean-Michel Sahut, Denis Schweizer, and Marta Peris-Ortiz	2022
	Technological innovations and their financial and socio-economic implications in the era of fourth industrial revolution	Muhammad Shahbaz, Shawkat Hammoudeh, and Muhammad Ali Nasir	2022
	Impacts and investigations of disruptive technologies for Industry 4.0	Victor Chang, Gary Wills, and Patricia Baudier	2022
	Sustainability in family business: Mechanisms, technologies and business models for achieving economic prosperity, environmental quality and social equity	Thomas Clauß, Paul Jones, and Sascha Kraus	2021
	Big data and network analysis in national innovation systems	Vania Sena, Nieves Arranz, Pablo Lucas, Han Woo Park, and Juan Carlos Fernandez de Arroyabe	2021
	Social-economic impacts of epidemic diseases	Dayong Zhang, Shunsuke Managi, and Zhuo (Adam) Chen	2021
	Digitalization adding value to healthcare	Yichuan Wang, William Yu Chung Wang, Minhao Zhang, Danae Manika, and Savvas Papagiannidis	2021
	Universities and social innovation for global sustainable development	Bo Göransson, Caroline Wigren-Kristoferson, and Letizia Donati	2021
	Peace engineering and innovation: A new techno-socio-economic development framework	Yorgos Marinakis, James Tangorra, Bernard Amadei, Ramiro Jordan, and Mark Nelson	2021
	Carbon cost and environment	Xiangzheng Deng	2021

model innovation" were converted to "business model innovation". The other text preprocessing tasks involved the removal of stop words, numbers, and non-English characters, including special characters and punctuation. The year of publication of each *TFSC* article was preserved for use as textual metadata.

3.1.2. Key steps in the STM

To explore the prominent topics in *TFSC* and their evolution over time, selecting an optimal number of topics is an essential step. Following the suggestions of previous research (Das et al., 2022; Sharma et al., 2022) based on the standard STM protocol (Roberts et al., 2019), we empirically identified the optimal number of topics for this study as 18. The optimal balance between topic meaningfulness (semantic coherence) and topic exclusiveness (exclusivity) guided the final selection of the number of latent topics. The pseudocode of the STM algorithm is provided below. A complete description of the implementation of the STM has been provided by previous studies (Roberts et al., 2016; Roberts et al., 2019).

Step 1. Estimate the topic prevalence parameter using log-normal distribution from the textual corpus of *TFSC* articles published between 1969 and 2022. This topic prevalence parameter represents each article as a weighted blend of topics.
Step 2. Estimate the topical content model parameter using a multinomial logit model to represent each topic as a weighted blend of terms.
Step 3. For each term in each *TFSC* article, a topic can be sampled using a core language model based on multinomial distribution over the topic prevalence parameter.
Step 4. For a given topic, a term can be sampled using the multinomial distribution function including article-level covariates and topic prevalence parameter values as arguments.

An STM-based approach allows metadata-based covariates (i.e., in the case of this study, the publication year of each *TFSC* article) to be used in the topic modelling process, which enables researchers to observe the influence of covariates on topical prevalence (Sharma et al., 2021). In this way, by taking publication year as a covariate, this study can facilitate the visualization of year-by-year variation in topic prevalence. This study employed the *tm* package for text preprocessing (Feinerer et al., 2008), the *stm* package for empirical analyses (Roberts et al., 2019), and *ggplot2* for the visualization of results (Wickham, 2011); all these approaches used R software.

3.2. Bibliometric analysis

This study features bibliometric analysis in the form of a citation analysis and a coauthorship analysis to uncover the top-cited articles and geographical dispersion of affiliated authors published in *TFSC* over time. Notably, bibliometric analysis is a well-established method for reviewing the performance and mapping the scientific character of scholarly research due to its objectivity, which is based on the use of quantitative or statistical techniques for analysis (Donthu et al., 2021; Kraus et al., 2022b; Lim et al., 2022b; Mukherjee et al., 2022). The software used for the bibliometric analysis were Gephi (Bastian et al., 2009) and VOSviewer (van Eck and Waltman, 2010).

4. Results

4.1. STM results

The STM is developed to answer RQ1 (What are the most prominent topics in *TFSC*, and how have these topics evolved over time?) and RQ2 (What variations in topical prevalence in *TFSC* over time?). Specifically, STM maps all *TFSC* articles to the extracted topics based on posterior probabilities, unlike other approaches that involve text classification based on predetermined categories.

Semantic coherence and topic exclusivity. All machine learning models suffer from issues related to explainability that make it difficult to perform a quality assessment of the results (Sharma et al., 2021). However, previous studies have suggested two measures that can be used to assess the topical quality of STM results: (i) visualizing semantic coherence and topic exclusivity scores and (ii) assessing the correlations among topics (Baker et al., 2021; Sharma et al., 2022).

Topics are considered to be distinct when the key terms associated with a topic are not frequently associated with other topics. Fig. 1 shows the map of semantic coherence and topic exclusivity scores. If two topics are not distinct, they are placed in the same space on the semantic coherence and topic exclusivity map (Sharma et al., 2021), which is not the case in Fig. 1, thus indicating that all topics are fairly separated and semantically distinct.

The correlations among topics are computed to assess their semantic association. A correlation of 0.7 or higher between two topics is undesirable because it indicates that the underlying terms that form the content of those topics are highly similar (Sharma et al., 2021), thus implying that the topic modelling results are not accurate due to a high probability that both the correlated topics refer to the same set of documents. The topic correlation matrix depicted in Fig. 2 shows that all correlation values are less than 0.2, which is indicative of good topic modelling results.

As the topics included in this study are extracted from a very high number of documents, it is possible that several documents discuss more than one topic. Negative or zero correlation confirms that the terms associated with topics are distinct. For example, the positive correlation between Topic 9 (energy, environment, and sustainable development) and Topic 14 (environmental regulation, carbon emission reduction, and technology innovation) is fair and intuitive, as Topic 9 focuses on research related to renewable energy, energy policy, environment degradation, and sustainable development (Omri et al., 2022; Pereira et al., 2022; Yu et al., 2022a, 2022b), whereas Topic 14 highlights issues related to technological advancements aimed at carbon emission reduction, policies for environmental regulation, and the transition towards a low-carbon economy based on the notion of the circular economy, artificial intelligence, and green innovations (Leitão et al., 2022; Lin and Ma, 2022; Wang et al., 2022c; Xie et al., 2022a). As both of these topics may occur in the same set of research articles, there is a high probability of the co-occurrence of similar terms such as “environment” and “emission”. Hence, the semantic associations among topics are intuitive and reflect the associations among diverse research interests with regard to common topics. The positive correlation between Topic 2 (the adoption and diffusion of technology and innovation) and Topic 5 (broadband, mobile, and digital currency) can be explained in terms of the convergence, adoption, and diffusion of new technologies, including broadband, mobile, web, and digital payment systems, including cryptocurrencies.

4.1.1. Most prominent topics in TFSC

The 18 major topics emerging from the STM are presented in the following, including the dominant topics, their top 10 constituent terms, and a few exemplary articles from *TFSC*, with the aim of illustrating the topical content presented in Table 2.

4.1.1.1. Topic 1. Technology assessment and society. This topic represents the associations among science, technology, and society, in which context scholars have proposed diverse perspectives on and frameworks for policy decision-making and technology assessment (Bauer and Kastenhofer, 2019; Delvenne and Parotte, 2019; van Est, 2019). Societal contexts shape the configuration, conception, adoption, and institutionalization of science, innovation, and technology (Kaplan et al., 2021), whereas the societal, economic, political, and ethical implications and the characteristics of innovation and technology highlight the importance of policy-making for the governance of science and technology (Tran and Daim, 2008). Technology assessment is used as a policy assessment tool to evaluate the unplanned and unanticipated societal impacts of the technological changes introduced by science and technology (Coates, 1976). These societal impacts may be a consequence of the introduction of a novel innovation or an expansion of

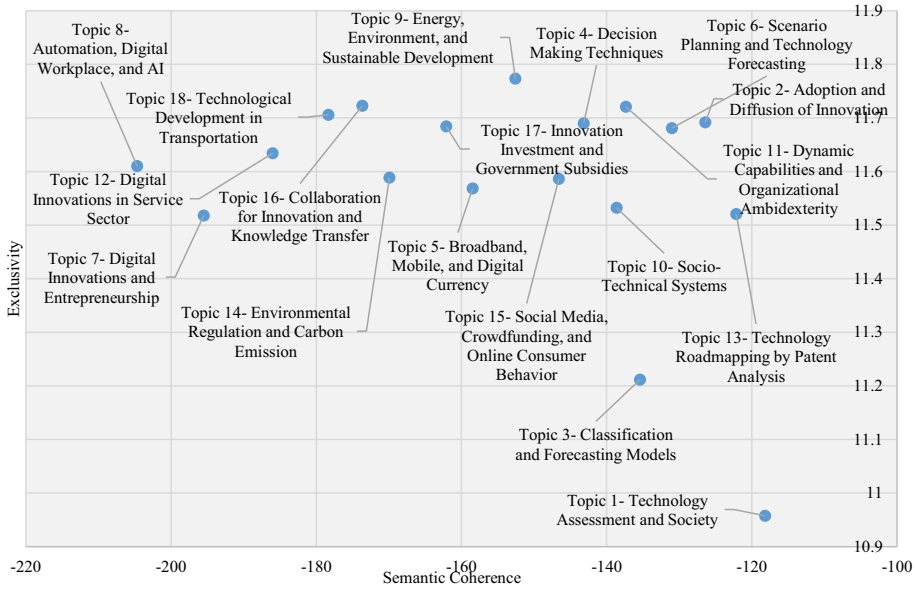


Fig. 1. Semantic coherence and topic exclusivity map.
Notes: Only short forms of topic labels are used due to visualization limitation. The complete topic labels are available in Table 2.

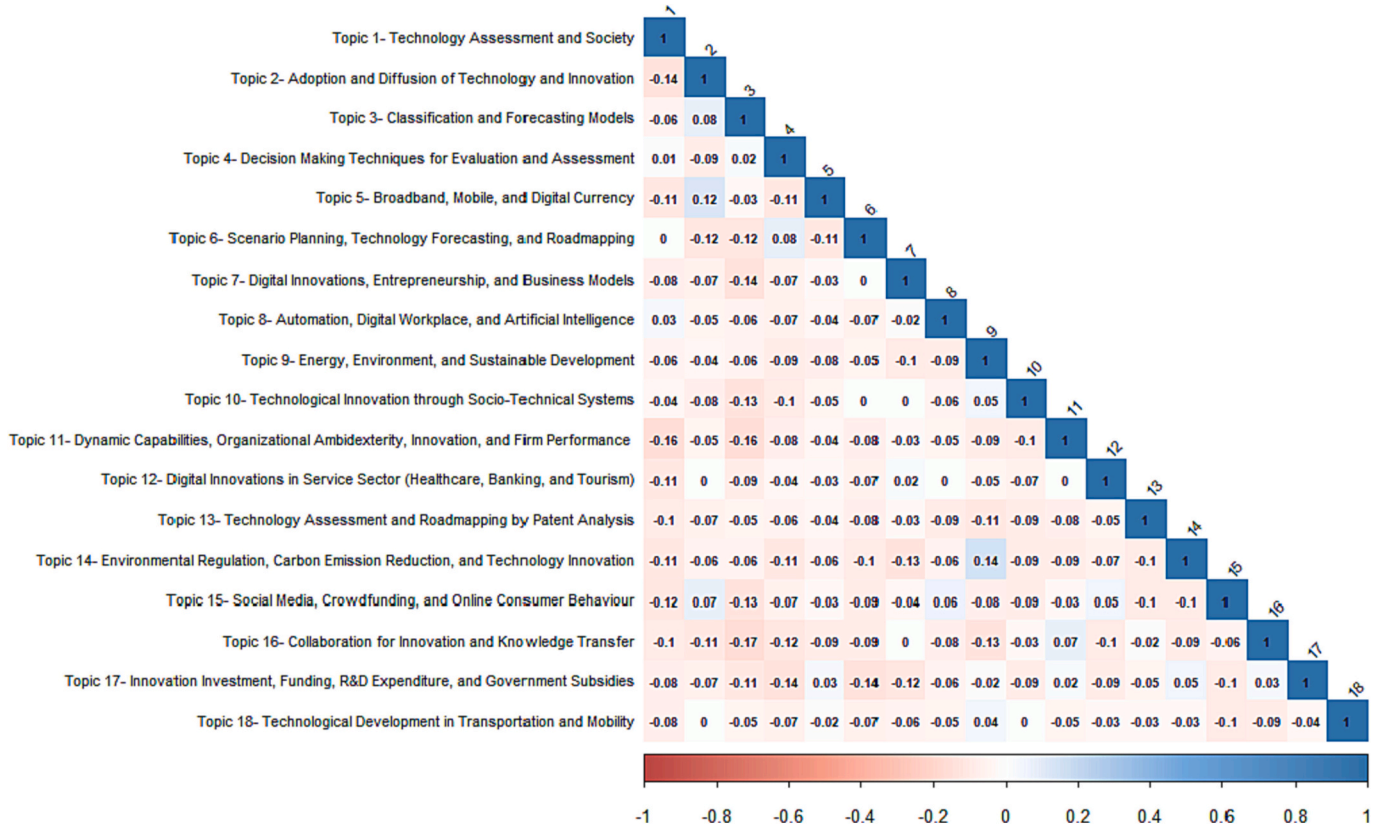


Fig. 2. Topic correlation matrix.
Notes: Negatively correlated topics are more distinct as terms with high probability of occurrence in given topic are unlikely to be present in other topics. Only short forms of topic labels are used due to visualization limitation. The complete topic labels are available in Table 2.

existing technology. Therefore, the scholarly significance of technology assessment has attracted interest from academic researchers in scientific communities, practitioners from the private sector, and policy-makers from parliamentary and policy-making bodies (Bauer and Kastenhofer, 2019; Tran and Daim, 2008; van Est, 2019).

4.1.1.2. Topic 2. Adoption and diffusion of technology and innovation. This topic explores scholarship regarding the adoption and diffusion of new technological advancements and innovations (Valor et al., 2022). Diffusion models are used to forecast future trends related to the conditional likelihood of the appropriation and dissemination of novel and innovative products and services in society (Turk and Trkman, 2012).

Table 2
Topic labels, top words, and exemplary studies.

Topic labels	Top 10 words by probability	Top 10 words by FREX	Exemplary studies
Topic 1. Technology Assessment and Society	Science, Technology Assessment, Social, Economic, System, Society, Political, Problem, Development, Environment	Constructive Technology Assessment, Military, Terrorism, Democratic, Democracy, Conflict, Society, Conflict, Peace Engineering, Public Participation	(Bauer and Kastenhofer, 2019; Delvenne and Parotte, 2019; Franks and Cohen, 2012; Hennen and Nierling, 2019; Kaplan et al., 2021; Tavella, 2016; Torgersen, 2019; Tran and Daim, 2008; van Est, 2019; van Merkerk and Smits, 2008)
Topic 2. Adoption and Diffusion of Technology and Innovation	Product Development, Technology Adoption, Technology Diffusion, Consumer, Innovation Diffusion, Advertising, Marketing, Retail, Modelling, Diffusion Model	Retail, Innovation Diffusion, Diffusion Process, Lotka-Volterra Model, Innovation Adoption, Product Design, Market Research, Customer Satisfaction, Customer Experience, Bass Model	(Cho et al., 2012; Duan et al., 2014; Dutta et al., 2017; Ferreira and Lee, 2014; Higgins et al., 2012; Lim et al., 2019; Sultanov et al., 2016; Tu et al., 2021; Turk and Trkman, 2012; Valor et al., 2022)
Topic 3. Classification and Forecasting Models	Forecasting Model, Prediction Model, Time Series Modelling, Probability, Logistic Modelling, Classification, Algorithm, Optimization, Machine Learning Model, Artificial Intelligence	Curve, Logistic Growth, Time Series Modelling, Forecasting Model, Hidden Markov Model, Prediction, Parameter, Ensemble, Logistic Model, Mathematical Model	(Biswas et al., 2022; Devezas and Miranda, 2022; Jabeur et al., 2022; Kamble et al., 2021; Li et al., 2021b; Schlembach et al., 2022; Sohrabpour et al., 2021; Xiao et al., 2021; Yu et al., 2022a; Zhukov et al., 2022)
Topic 4. Decision Making Techniques for Evaluation and Assessment	Multiple-Criteria Decision-Making, Group Decision Making, Delphi, Evaluation, Expert, Fuzzy, Decision Analysis, Quantitative Assessment, Decision Support System, Multi Criteria Analysis	Fuzzy Topsis, Analytic Hierarchy Process, Delphi Technique, Decision Making, Decision Analysis, Evaluation, Expert, Delphi Analysis, Impact Analysis, Consensus	(Irfan et al., 2022; Krawinkler et al., 2022; Mahmud et al., 2022; Peppel et al., 2022; Rodríguez et al., 2022; Xuan, 2022; Yalcin et al., 2022; Zeng et al., 2022a; Zeng et al., 2022b; Zhang et al., 2022)
Topic 5. Broadband, Mobile, and Digital Currency	Cryptocurrency, Blockchain, Mobile Phone, Competition, Telecommunication, Broadband, Regulatory, Mobile Communication, Digital Payment, Mobile Data Service	Volatility, Bitcoin, Cryptocurrency, Telecommunication, Broadband, Broadcasting, Mobile Phones, Multimedia, Stock Market, Television	(Ante et al., 2021; Asongu et al., 2021; Gaies et al., 2021; García-Monleón et al., 2021; Lantano et al., 2022; Le et al., 2021; Li et al., 2021a; Umar et al., 2021; Wang et al., 2022e; Yi et al., 2022)
Topic 6. Scenario Planning, Technology Forecasting, and Roadmapping	Project Management, Portfolio Planning, Scenario Planning, Urban Planning, Management, Technology Roadmapping, Strategic Planning, Strategic Foresight, Foresight Process, Smart City	Scenario Planning, Back Casting, Strategic Foresight, Planning Process, Resilience, Technology Roadmapping, Emergency Management, Corporate Foresight, Scenario Development, Urban Planning	(Al-Mutairi et al., 2022; Andersen et al., 2021; Burt et al., 2021; Chakraborty et al., 2022; Douglas et al., 2021; Gallego et al., 2021; Gupta et al., 2022; Hakmaoui et al., 2022; Yuskevich et al., 2021a; Yuskevich et al., 2021b)
Topic 7. Digital Innovations, Entrepreneurship, and Business Models	Research, Innovation, Ecosystem, Literature, Digital, Business Model, Smart City, Innovation Ecosystem, Digital Entrepreneurship, Innovation Management, Service Innovation	Systematic Literature Review, Smart City, Ecosystem, Innovation Ecosystem, Discovery, Digital Entrepreneurship, Business Model, 3D-Printing, Social Innovation, Business Model Innovation,	(Battisti et al., 2022; Bunduchi et al., 2022; Chen et al., 2022b; Füller et al., 2022; Liao et al., 2022; Modgil et al., 2022; Palmié et al., 2022; Schiavone et al., 2021; Şimşek et al., 2022; Snihur et al., 2021)
Topic 8. Automation, Digital Workplace, and Artificial Intelligence	Health, Covid, Human, Work, Employment, Labor Market, Artificial Intelligence, Automation, Robot, Technology	Covid, Pandemic, Robot, Creativity, Job, Revolution, Lockdown, Mortality, Workforce, Employment	(Allal-Chérif, 2022; Arias-Pérez and Vélez-Jaramillo, 2022; Egana-delSol et al., 2022a; Egana-delSol et al., 2022a; Johnson et al., 2022; Lee and Lee, 2021; Maran et al., 2022; Nørskov et al., 2022; Shareef et al., 2021; Tan et al., 2021)
Topic 9. Energy, Environment, and Sustainable Development	Energy, Environment, Sustainability, Sustainable Development, Water, Climate Change, Electricity, Economic, Resource, Consumption	Renewable Energy, Natural Gas, Environment Sustainability, Electricity, Energy Policy, Forest, Energy System, Alternative Energy, Eco Innovation, Bioenergy	(Abbasi et al., 2022; Awijen et al., 2022; Cordroch et al., 2022; Dwivedi et al., 2022; Kopka and Grashof, 2022; Lu et al., 2022; Omri et al., 2022; Pereira et al., 2022; Wang et al., 2022a; Yu et al., 2022b)
Topic 10. Technological Innovation through Socio-Technical Systems	Technological Innovation System, Innovation System Transition, Innovation Policy, Governance, Socio-Technical System, Transformation, Sustainability Transition, Evolutionary Economics, Socio-Technical Innovation, Social Innovation	Technological Innovation System, Sustainability Transition, Socio-Technical System, Innovation System, Technical Transition, Transition Management, Innovation Policy, System Building, Transformation, Actor Network Theory	(Fischer et al., 2022; Jiang, 2022; Jiang and Liu, 2022; Kanger et al., 2022; Ko et al., 2021; Lee et al., 2022b; Lovell et al., 2022; Mirzadeh Phirouzabadi et al., 2022; Ortt and Kamp, 2022; Quevedo Cascante et al., 2022)
Topic 11. Dynamic Capabilities, Organizational Ambidexterity, Innovation, and Firm Performance	Performance, Firm, Financial Performance, Innovation, Business, Environment, Dynamic Capability, Organizational Ambidexterity, Competitive Advantage, Intellectual Capital	SMEs, Agility, Firm Performance, Dynamic Capability, Financial Performance, Competitive Advantage, Ambidexterity, Organizational Performance, Performance Assessment, Product Innovation	(Alkaraan et al., 2022; Chatterjee et al., 2022a; Dixit et al., 2022; Gastaldi et al., 2022; Hassani and Mosconi, 2022; Huang et al., 2022; Jafari-Sadeghi et al., 2022; Sultana et al., 2022; Troise et al., 2022; Xie et al., 2022b)
Topic 12. Digital Innovations in Service Sector (Healthcare, Banking, and Tourism)	Service, Healthcare, Internet, Big Data, Information System, IOT, Blockchain, eHealth, Circular Economy, Big Data Analytics	IOT, Hospital, Blockchain, Circular Economy, Healthcare Service, Cloud Computing, Supply Chain, Google Trends, Recycling, Tourism	(Arfi et al., 2021; Balasubramanian et al., 2021; Ben Arfi et al., 2021; Chiang et al., 2022; Cuomo et al., 2022; Huarng et al., 2022; Manthiou and Klaus, 2022; Rezaei et al., 2021; Schiavone et al., 2022; Tortorella et al., 2021)
Topic 13. Technology Assessment and Roadmapping by Patent Analysis	Patent, Invention, Patent Analysis, Technological Development, Emerging Technology, Intellectual Property, Nanotechnology, Convergence, Network Analysis, Scientific Trend	Patent, Patent Analysis, Patent Citation, Solar Cells, Semiconductor Industry, Standardization, Trademark, Technology Convergence, Technology Lifecycle, Technology Intelligence	(Baumann et al., 2021; Choi et al., 2022; Fernández et al., 2022; Hain et al., 2022; Jeon et al., 2022; Losacker, 2022; Trappey et al., 2021; Zamani et al., 2022; H. Zhang et al., 2021; Zhu and Motohashi, 2022)
Topic 14. Environmental Regulation, Carbon Emission	Environmental Regulation, Energy Efficiency, Agricultural Productivity, Carbon Emission,	Carbon Emission, Environment Regulation, Total Factor Productivity, Data Envelopment Analysis, Emission Reduction, Emissions	(Huo et al., 2022; Leitão et al., 2022; R. Li et al., 2022; Lin and Ma, 2022; Miao and Chen, 2022; M. Song et al., 2022a; Tao

(*continued on next page*)

Table 2 (*continued*)

Topic labels	Top 10 words by probability	Top 10 words by FREX	Exemplary studies
Reduction, and Technology Innovation	Climate Change, Economic Growth, Pollution, Mitigation, Agricultural Innovation, Policy	Trading, General Equilibrium, Productivity Growth, Urbanization, Technical Efficiency	et al., 2022; Wang et al., 2022c; Wang et al., 2022d; Xie et al., 2022a)
Topic 15. Social Media, Crowdfunding, and Online Consumer Behaviour	Online, Social Media, Social Networking, Crowdfunding, Trust, Influence, Perception, Attitude, Intention, Consumer Behaviour	Social Media, Social Networking, Technology Acceptance Model, Intention, Acculturation, Social Commerce, Crowdfunding, Social Support, Behavioural Intention, Privacy Concern	(Chatterjee et al., 2022b; De Luca et al., 2022; Djimesah et al., 2022; Mäntymäki et al., 2022; Masuda et al., 2022; Piazza et al., 2022; Ramjattan et al., 2022; Staniewski and Awruk, 2022; Tandon et al., 2022; Wang et al., 2022b)
Topic 16. Collaboration for Innovation and Knowledge Transfer	Knowledge, Innovation, Network, Technology Transfer, Collaboration, Entrepreneurship, Open Innovation, Knowledge Management, Social Capital, University-Industry Collaboration	Knowledge Transfer, Technology Transfer, Open Innovation, External Knowledge, Regional Innovation System, Higher Education, Partnership, Public Research, Collaboration, National Innovation System	(Albats et al., 2022; Aldawod, 2022; Borah and Ellwood, 2022; Feng et al., 2022; Janssen and Abbasiharofteh, 2022; Meissner et al., 2022; Patnaik et al., 2022; Riandita, 2022; Roncancio-Marin et al., 2022; Zoppelletto and Bullini Orlandi, 2022)
Topic 17. Innovation Investment, Funding, R&D Expenditure, and Government Subsidies	Innovation, Investment, Economic, Government Subsidy, Development, Technological Innovation, Economic Growth, Policy, Globalization, Financial Development	Financing Innovation, Investment, Globalization, Government Subsidy, Technological Innovation, Digital Divide, Developing Countries, Technology Spillover, Expenditure, Technological Diversification	(Boeing et al., 2022; Chen et al., 2022a; Hu, 2021; Lee et al., 2022a; Liang et al., 2022; Shi et al., 2022; Song et al., 2022b; Wu et al., 2022; D. Yuan et al., 2022; Zahler et al., 2022)
Topic 18. Technological Development in Transportation and Mobility	Automobile Industry, Technology, Production, Manufacturer, Transportation, Electric Vehicle, Autonomous Vehicle, Technological Development, Intelligent Transport, Electric Mobility	Electric Vehicle, Hydrogen, Technological Change, Automotive Industry, Charging, Freight, Transport, Autonomous Vehicle, Transportation System, Lithium	(Babar and Ali, 2021; Benzidia et al., 2021; Bridgelall and Stubbing, 2021; Doctor et al., 2022; Ghazy et al., 2022; James et al., 2022; Jun et al., 2022; Llopis-Albert et al., 2021; Tijan et al., 2021; P. X. Yuan and Cai, 2021)

The Bass diffusion model (Bass, 1969), which was introduced in 1969, identified the external and internal macrolevel factors that influence the innovation diffusion process at the theoretical level. The pioneering work of Bass (1969) motivated other scholars to adapt and extend the innovation diffusion model using market segmented learning (Ferreira and Lee, 2014) and the exponential-function improved model (Han et al., 2022). Research on the adoption and diffusion of innovation has also attempted to explain the complexities associated with forecasting the diffusion and penetration of new technologies such as mobile telephones in Kazakhstan (Sultanov et al., 2016), iOS and Android handsets (Dutta et al., 2017), broadband in European countries (Turk and Trkman, 2012), and smart thermostats (Tu et al., 2021), among others.

4.1.1.3. Topic 3. Classification and forecasting models. This topic addresses research related to classification and prediction models based on statistical-, machine learning-, and artificial intelligence-based approaches to the task of understanding complex social mechanisms (Erspamer et al., 2022; Devezas and Miranda, 2022), human behaviour (Sohrabpour et al., 2021), organizational processes (Kamble et al., 2021; Yu et al., 2022a), and environmental issues (Xiao et al., 2021). *TFSC* has been the outlet most preferred by researchers who desire to contribute quality work related to the use of machine learning and artificial intelligence for classification and prediction. Specifically, the contemporary advancements made in this domain have emphasized the applicability of these models in a variety of situations, ranging from predicting the distribution of Olympic medals (Schlembach et al., 2022), forecasting the evolution of the iPhone product family (Biswas et al., 2022), logistic modelling of the evolution of the COVID-19 pandemic (Devezas and Miranda, 2022), evaluating the factors associated with entrepreneurial opportunities (Jabeur et al., 2022), predicting the adoption of blockchain technologies in the supply chain (Kamble et al., 2021), and forecasting macroeconomic issues such as crude oil price (Li et al., 2021b), among others.

4.1.1.4. Topic 4. Decision-making techniques for evaluation and assessment. This topic focuses on comprehensive research on solving individual and group decision-making problems that involve multicriteria optimization in different process, people, technology, and organizational contexts (Mahmud et al., 2022; Yalcin et al., 2022). The need for quick, accurate, and cost-effective large-scale approaches to group decision-making in business organizations has motivated scholars to propose various advancements, such as big data-driven fuzzy logic methods (Xuan, 2022), minimum cost consensus models (Rodríguez et al., 2022), Delphi-based scenario planning (Peppel et al., 2022), and heuristic-based data-driven mathematical optimization (Krawinkler et al., 2022). These techniques assist managers in addressing business bottlenecks, identifying barriers, prioritizing the business opportunities offered by new technologies, and optimizing productivity and profits. These decision-making approaches have allowed their users to evaluate a variety of complex business decision-making problems, such as the barriers to the adoption of biomass energy (Irfan et al., 2022), the consequences of digital reform in electronic communication equipment manufacturing companies (Zeng et al., 2022b), decision-making in the circular economy (Xuan, 2022), and the bottleneck associated with the adoption of green energy (Krawinkler et al., 2022).

4.1.1.5. Topic 5. Broadband, mobile, and digital currency. This topic deals with research concerning broadband internet, mobile phones, mobile application services, internet telephony, digital convergence, and digital currencies such as Bitcoin. Technologies related to the internet and broadband have revolutionized the way in which information is communicated and consumed (Yoon et al., 2005), and mobile-based products and services have emerged as a threat to traditional products and services (Asongu et al., 2021; Lantano et al., 2022). Moreover, globalized digital currencies and cryptocurrencies such as Bitcoin have been viewed as the biggest financial innovation associated with Industry 4.0 (Le et al., 2021; Li et al., 2021a). The potential benefits and unique characteristics of decentralized cryptocurrencies have been discussed and examined by various scholars working in the domain of finance and investment (Ante et al., 2021; Gaies et al., 2021; García-Monleón et al., 2021; Wang et al., 2022e). However, the rapid growth and expanding applications of cryptocurrencies have raised concerns regarding extreme volatility and return-for-risk (Yi et al., 2022).

4.1.1.6. Topic 6. Scenario planning, technology forecasting, and roadmapping. This topic consists of academic and practice-oriented scholarly work on scenario planning, technology forecasting, and technology roadmapping. Technology roadmapping is an established innovation management tool that is used to develop a technology roadmap. A technology roadmap is a long-term strategy to prioritize the development of new technologies and innovative products and services (Park et al., 2020). Technology roadmapping is an iterative process that

requires collaboration among multiple stakeholders who utilize analytical and theoretically robust methods to develop a technology roadmap based on commercial and technological perspectives (Chakraborty et al., 2022; Yuskevich et al., 2021b). Model-based technology roadmapping (Yuskevich et al., 2021a), scenario-based modelling (Al-Mutairi et al., 2022; Burt et al., 2021), and portfolio planning (Gupta et al., 2022) help organizations formulate strategies that focus on the long-term technology development goals of high-priority innovation.

4.1.1.7. Topic 7. Digital innovations, entrepreneurship, and business models. This topic highlights research on digital innovations, entrepreneurship, and contemporary business models. Digital innovations based on information technologies have led to diverse technological changes in business, government and public systems, and society. Digital product innovation involves the development of novel products and services through the radical reconfiguration of available physical resources and digital technologies (Bunduchi et al., 2022). For example, "born digital" marketplaces such as Amazon and eBay disrupt the market by offering new products or services (Palmié et al., 2022). These digital innovations have motived the rise of technologically focused entrepreneurs empowered by data-driven decision-making based on insights drawn from intelligent data and artificial intelligence-enabled business models (Battisti et al., 2022; Füller et al., 2022). Digital entrepreneurship is signified by the entrepreneurial opportunities created by leveraging digital platforms and digital infrastructure for buying and selling products and services, which may consist of procurement of raw material, production, marketing, and distribution (Modgil et al., 2022; Schiavone et al., 2021; Şimşek et al., 2022).

4.1.1.8. Topic 8. Automation, digital workplace, and artificial intelligence. This topic represents research on automation (Egana-delSol et al., 2022a), digital workplaces (Maran et al., 2022), and artificial intelligence-based services that can substitute for human intervention (Lee and Lee, 2021). Automation innovations based on artificial intelligence can radically redefine the ways in which society adopts and consumes technology (Shareef et al., 2021). These digital innovations efficiently execute repetitive manual tasks in predictable environments to enable decision-makers to focus on higher-value activities. The technological advances introduced in the fourth industrial revolution, such as automation, robotics, artificial intelligence, and big data analytics, have created opportunities for the enhancement of productivity, quality, and efficiency (Johnson et al., 2022). However, the undesired societal consequences of automation have led to the emergence of several technological risks and ethical issues (Arias-Pérez and Vélez-Jaramillo, 2022; Tan et al., 2021). The negative consequences of automation involve the undesirable substitution of human labour, which may have a detrimental effect on traditionally disadvantaged groups (Egana-delSol et al., 2022a; Egana-delSol et al., 2022b). Hence, it is necessary to reassess the opportunities and challenges associated with the use of robotics and autonomous systems and to research ways of mitigating the corresponding negative consequences, especially for vulnerable groups in society (Fruehwirt and Duckworth, 2021; Nørskov et al., 2022).

4.1.1.9. Topic 9. Energy, the environment, and sustainable development. This topic highlights a diverse set of intellectually interconnected issues related to energy, the environment, and sustainable development. The seventh goal included in the Sustainable Development Goals (SDGs) pursued by the United Nations (UN) highlights the need to provide affordable clean energy to human society. The commitment of *TFSC* scholars to pursue a low-carbon future is evident from the extant research on sustainable energy systems (Pereira et al., 2022), renewable energy deployment (Awijen et al., 2022), energy efficiency (Cordroch et al., 2022), and the use of digital innovation to curb energy poverty (Wang et al., 2022a). Scholars have acknowledged the significance of technological innovation for sustainable development (Abbasi et al., 2022) and proposed responsible approaches to production by integrating the circular economy and Industry 4.0 (Dwivedi et al., 2022). The combined efforts of society, businesses, and the government to pursue industrial decarbonization, limit the use of fossil fuels, and reduce the carbon emissions associated with the energy sector have strong implications for sustainable development goals (Yu et al., 2022b).

4.1.1.10. Topic 10. Technological innovation through sociotechnical systems. This topic includes multidisciplinary studies that examine the technical and social aspects of technological innovations pertaining to sociotechnical systems. The effectiveness, efficiency, and impact of any technological innovation depend on the complex dynamic interactions among various actors, such as people, organizations, technologies, governments, and the environment. The multiple causal relationships among these actors form an interconnected multiparty system that complicates the process of transitioning to a sociotechnical system (Jiang, 2022). Hence, the adoption of sociotechnical systems has attracted scholarly attention, and researchers have advocated the coevolution of technology and society (Lee et al., 2022b). The adoption of sociotechnical systems and the associated sociotechnical transitions have been explored in different contexts by scholars published in *TFSC*, such as aquaculture innovation in fish farming (Quevedo Cascante et al., 2022), eHealth innovations (Jiang, 2022), wind power industry innovations (Jiang and Liu, 2022), and the innovations hade by competence centres in support of the digitalization of SMEs (Prodi et al., 2022), among others.

4.1.1.11. Topic 11. Dynamic capabilities, organizational ambidexterity, innovation, and firm performance. This topic represents scholarship exploring the interconnections among agility, dynamic capabilities, organizational ambidexterity, and firm performance. Business organizations strive to achieve agility, develop ambidexterity, and enhance their dynamic capabilities to sustain organizational performance and competitive performance in turbulent environments (Chatterjee et al., 2022a; Hassani and Mosconi, 2022; Jafari-Sadeghi et al., 2022). Environmental uncertainties and intense competition require firms to adapt to new technologies quickly and capitalize on their innovative capabilities (Sultana et al., 2022; Troise et al., 2022). Hence, the ambidextrous innovation capabilities of a firm facilitate the exploration and exploitation of both *incremental innovation* and *radical innovation* to achieve sustainable growth and competitive advantage (Dixit et al., 2022; Gastaldi et al., 2022). These constructs have been explored by various scholars in different contexts and organizational settings, such as the adoption of Industry 4.0 (Dixit et al., 2022), the adoption of smart technologies (Gastaldi et al., 2022), and the adoption of social media analytics by manufacturing SMEs (Hassani and Mosconi, 2022), among others.

4.1.1.12. Topic 12. Digital innovations in the service sector (health care, banking, and tourism). This topic focuses on research exploring digital innovations in the service sector. Digital innovations are radically disrupting the service sector, in which context innovative products and services lead to changes in human lifestyles and reshape the ways in which organizations engage with their stakeholders (Tortorella et al., 2021). Previous studies have confirmed that service-intensive organizations, especially organizations in the health care, tourism, hospitality, and banking industries, can benefit significantly from digital innovations such as blockchain technologies (Balasubramanian et al., 2021), the Internet of Things (IoT) (Arfi et al., 2021; Ben Arfi et al., 2021), service robots (Chiang et al., 2022), wearable health care devices (Huarng et al., 2022), and eHealth technology, including telemedicine and electronic health records (Rezaei et al., 2021). However, the enormous benefits of these disruptive technologies also raise concerns for scholars, such as concerns related to trust (Arfi et al., 2021), stakeholder

readiness for adoption (Balasubramanian et al., 2021), perceived risk and cost (Ben Arfi et al., 2021), issues with service quality (Chiang et al., 2022), data privacy (Huarng et al., 2022), and ethical challenges (Rezaei et al., 2021), among others.

4.1.1.13. Topic 13. Technology assessment and roadmapping using patent analysis. This topic pertains to technological forecasting research on the assessment of global research trends through analysis of patents and research articles. Forecasting technology trends, scientific advancement, technological innovation, and technology convergence have always attracted a significant amount of attention from contributors to *TFSC* (Trappey et al., 2021; Zhang et al., 2021). Predicting innovations, scientific breakthroughs, and technological convergence requires the identification, assessment, and profiling of emerging technologies as documented in patents and related scientific publications (Jeon et al., 2022; Zamani et al., 2022). Patent documents are a rich source of information concerning energy technologies that can be leveraged by advanced text analytics approaches based on machine learning (Zhang et al., 2021), network analysis based on the exponential random graph model (Losacker, 2022), deep learning (Choi et al., 2022), and artificial intelligence methods such as graph convolutional networks (Zhu and Motohashi, 2022). Patent landscaping is a promising method for data-driven technology roadmapping that researchers and policy-makers can use to identify the technological opportunities offered by emerging technologies and to track innovation diffusion (Fernández et al., 2022; Hain et al., 2022).

4.1.1.14. Topic 14. Environmental regulation, carbon emission reduction, and technology innovation. This topic addresses issues pertaining to environmental regulation, carbon dioxide emission reduction, and innovations related to green technology and the control of air pollution. Environmental regulations aimed at mitigating the negative impact of the intensive exploitation of natural resources and facilitating reductions in emissions have led to increased scholarly attention to this topic and relevant discussions among academics, practitioners, and policy-makers. Socioeconomic factors related to the attempt to establish an optimal balance between environmental sustainability and economic development to protect the environment from global warming and greenhouse gas emissions have motivated scholars to revisit established hypotheses such as the environmental Kuznets curve and the Porter hypothesis (Wang et al., 2022c). The need to sustain economic growth without damaging the environment has also accelerated the development of green technology innovations (Lin and Ma, 2022), low carbon development (Wang et al., 2022c), technological advancements in support of energy efficiency (Wang et al., 2022a, 2022b, 2022c, 2022d, 2022e; Xie et al., 2022a), and environmental regulation policies (Huo et al., 2022; Song et al., 2022a), among others.

4.1.1.15. Topic 15. Social media, crowdfunding, and online consumer behaviour. This topic emphasizes research on online consumer behaviour, including the actions and interactions of people with internet-based services, websites, and other information technology applications. The digital revolution has disrupted the ways in which people form interaction groups and establish digital relationships on online social media (Ramjattan et al., 2022). Digital communication tools and platforms are increasingly used by entrepreneurs to highlight potentially innovative business ideas and raise financial capital through crowdfunding (Djimesah et al., 2022). Simultaneously, angel investors and venture capitalists leverage the 'wisdom of the crowd' to source innovative business ideas in a cost-effective and risk-free way (Piazza et al., 2022). Similarly, new digital platforms such as social networking sites are used by business organizations to exchange crucial information and improve stakeholder engagement (De Luca et al., 2022). Moreover, the user-generated content contained on online social media platforms has ample business value. Research has confirmed that user-generated content produced by social media-based influencers can shape the purchasing decisions of consumers (Masuda et al., 2022; Staniewski and Awruk, 2022). However, the ubiquity of social media and digital platforms has negative behavioural consequences that have deep impacts on the quality of users' personal lives (Chatterjee et al., 2022b) as well as their mental well-being and behaviour (Staniewski and Awruk, 2022).

4.1.1.16. Topic 16. Collaboration for innovation and knowledge transfer. This topic addresses research that explores the roles of joint undertakings, collaboration, strategic partnerships, and networking between academic institutions and industrial organizations with respect to the development of innovation ecosystems and emergent entrepreneurship. The university-industry collaboration and innovation network formed by entrepreneurial universities have led to solutions to complex societal problems related to sustainability (Riandita, 2022; Zoppelletto and Bullini Orlandi, 2022) and the creation of economic value for society (Roncancio-Marin et al., 2022). The predominant research concerning this topic explores key issues related to knowledge and technology transfer in university-industry collaboration (Meissner et al., 2022), the impact of university-industry collaboration from a societal perspective (Roncancio-Marin et al., 2022), intraorganizational dynamics such as power and politics (Patnaik et al., 2022), conflicts (Borah and Ellwood, 2022), and the role of digital intermediaries in facilitating such collaborations (Albats et al., 2022).

4.1.1.17. Topic 17. Innovation investment, funding, R&D expenditures, and government subsidies. This topic includes research on aspects of financing that are related to innovation such as government support, subsidies, investments, and the appropriation of expenditures to sustain research and development. Financial obstacles have been found to constitute the main barrier to innovation activities (Zahler et al., 2022). To make sustain efforts towards innovation, firms seek government subsidies, as the government provides funds after properly evaluating the social benefits of the innovation in question (Wu et al., 2022). State financial interventions in support of the indigenous innovation efforts of early entrepreneurs facing financial constraints have been found to have broader economic effects (Boeing et al., 2022; Lee et al., 2022a). Hence, government-subsidized firms are more able to sustain technological innovation and generate economic value based on innovation (Liang et al., 2022).

4.1.1.18. Topic 18. Technological development in transportation and mobility. This topic focuses on research on technological advancements in transportation and mobility. The automobile industry has undergone a massive digital transformation in relation to Industry 4.0, which has led to the introduction of disruptive transportation technologies such as electric vehicles, hybrid vehicles, autonomous vehicles, electric aircraft, and e-navigation-based maritime transport (Llopis-Albert et al., 2021; Tijan et al., 2021; Yuan and Cai, 2021). The predominant research concerning this topic examines multiple factors such as the market competitiveness of these advancements (Babar and Ali, 2021), buyers' perspectives on these disruptive transportation technologies, such as electric and hybrid vehicles (Benzidia et al., 2021), the demand and annual trends associated with these advancements (Bridgelall and Stubbing, 2021), the impact of autonomous vehicle firms on the national economy (Jun et al., 2022), and the impact of the overall digital transformation of the automobile industry (Llopis-Albert et al., 2021).

4.1.2. Temporal variations in topical prevalence in TFSC

Building on the discussion pursued in the previous section, this section explores the temporal variations in topical prevalence in *TFSC*. To explore the evolution of prominent topics in *TFSC*, this study includes publication year as a covariate in the STM (Roberts et al., 2016).

Fig. 3 provides an overview of the temporal dynamics associated with topical prevalence and illustrates the changes in the popularity of

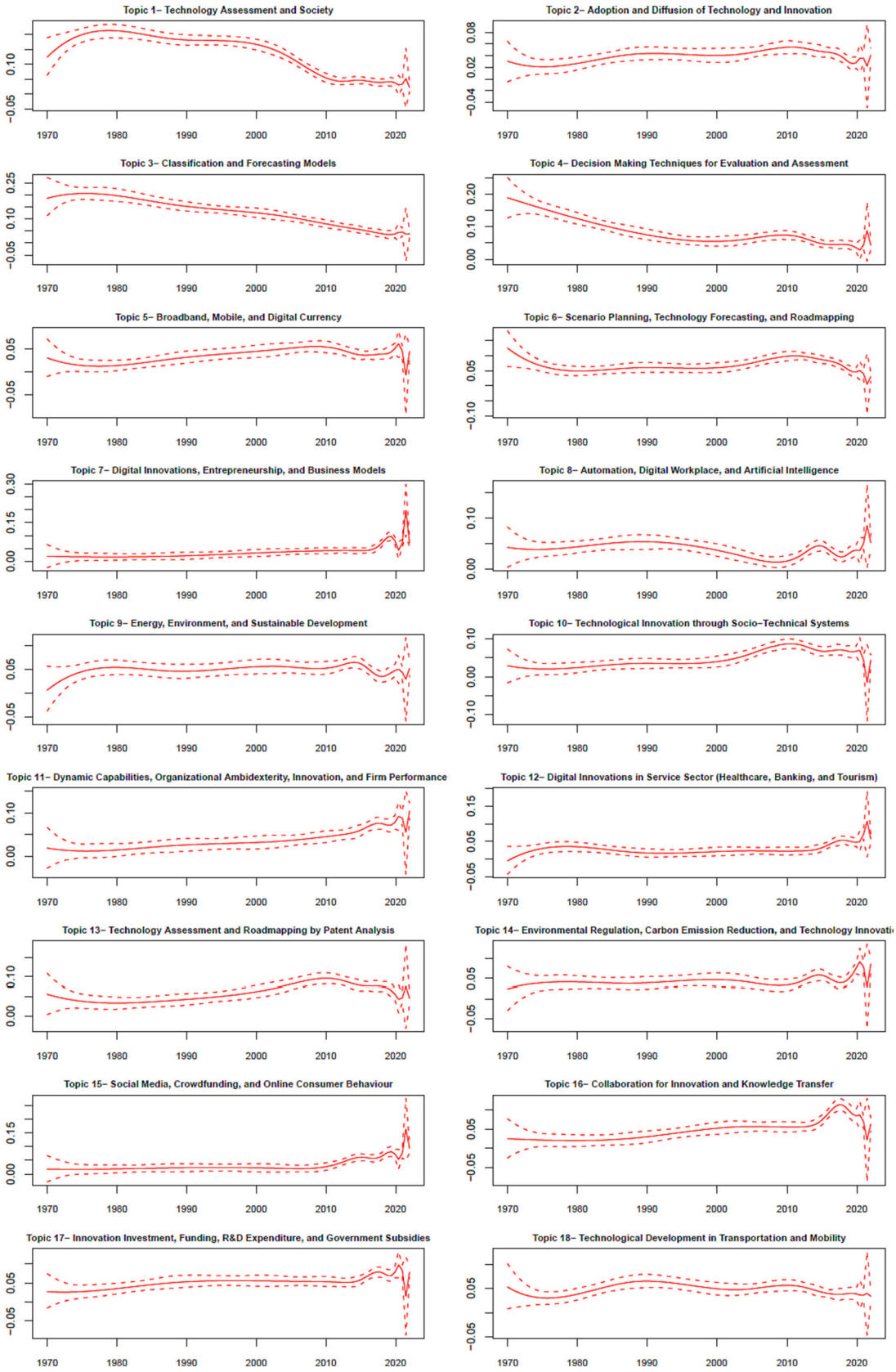


Fig. 3. Estimated topic prevalence with 95 % confidence intervals.

each topic between 1969 and 2022. Given that the forecasting of future trends is dependent on the ability to understand temporal variations (e.g., rising and declining topical trends over time) (Lim et al., 2023), topics that exhibit rising trends represent hotspots of scholarly interest that drive future scholarship. These academic hotspots are also known as "hot topics" or "future research frontiers", and they inform and shape the directions of future research (Baker et al., 2021; Sharma et al., 2022). Topics that exhibit declining temporal trends reflect decreasing popularity or research interest, and are thus often known as "cold topics"; such topics are unlikely to receive continued attention at a high level unless that attention is stimulated, for example, by an externality that immediately increases their relevance exponentially (e.g., crises or international agendas).

Notably, Topic 5 (broadband, mobile, and digital currency), Topic 11 (dynamic capabilities, organizational ambidexterity, innovation, and firm performance), Topic 12 (digital innovations in the service sector – health care, banking, and tourism), Topic 16 (collaboration for innovation and knowledge transfer), and Topic 17 (innovation investment, funding, R&D expenditures, and government subsidies) can be seen to receive increasing scholarly interest. These trends are consistent with the findings of previous studies that have explored *TFSC* using traditional bibliometric methods and found that technology transfer, digital innovations, dynamic capabilities, and internet-based technological diffusion shape future research directions in the context of *TFSC* (Singh et al., 2020b).

In addition, it is worth noting that Topic 7 (digital innovations, entrepreneurship, and business models) exhibits a rising trend in the new millennium, when the proliferation of the internet had a significant impact on businesses, resulting in the emergence of new business models. Furthermore, Topic 10 (technological innovation through sociotechnical systems) exhibits a rising trend until 2010, after which research interest starts to decline. One possible reason for this trend may be the effects of the deep penetration and adoption of information systems in all sectors on societies, which have caused these systems to become so ubiquitous that research interest has declined. A similar trend can be seen in the case of Topic 13 (technology assessment and roadmapping using patent analysis), which features a rising trend until 2010 and then a declining trend in subsequent years. In contrast, the rise of social media and social networking sites following the period from 2000 to 2005 has attracted significant research interest, which is clearly evident in the topical trend exhibited by Topic 15 (social media, crowdfunding, and online consumer behaviour), which features an upwards trend after 2005.

Similarly, Topic 1 (technology assessment and society), Topic 3 (classification and forecasting models), and Topic 4 (decision-making techniques for evaluation and assessment) exhibit declining trends. It is worth noting that Topic 1 and Topic 3 account for nearly 17 % of the total amount of research published in *TFSC*. However, the heavy exploration of these topics has led to intellectual maturity that motivates researchers to explore new avenues of investigation.

Finally, Topic 6 (scenario planning, technology forecasting, and roadmapping) exhibits a stable research interest during the 1969 to 2010 period but a declining trend thereafter. The same is true of Topic 18 (technological development in transportation and mobility), which initially attracted a significant amount of research interest, but exhibits a declining trend over the past decade. The rest of the topics exhibit either a stable or an erratic trend.

4.2. Bibliometric results

Bibliometric analysis is conducted to answer RQ3 (What are the publication trends exhibited by TFSC over time?), RQ4 (What are the most influential articles in TFSC, and how have they evolved over time?), and RQ5 (What is the geographical dispersion of the authors published in TFSC, and how has this dispersion evolved over time?). More specifically, a performance analysis of productivity is used to address RQ3 and a similar analysis of impact or influence is used to address RQ4 (Donthu et al., 2021), whereas science mapping process using coauthorship analysis is implemented to elucidate the authors' geographical dispersion to address RQ5 (Mukherjee et al., 2022).

4.2.1. Publication trends in TFSC

This section answers RQ3 (What are the publication trends exhibited by *TFSC* over time?). Fig. 4 illustrates the publication trends associated with *TFSC*, indicating a gradual increase in the publications included in the journal from 1969 to 2013, which is followed by a sudden and significant surge in the number of publications. *TFSC's* publication trends indicate significant growth mainly due to the journal's commitment to promoting research that addresses trending and pressing issues, which have increased over the years. Over time, the journal has become more global, and its scope has expanded to encompasses scholars worldwide, leading to increasing publication trends since its inception.

4.2.2. Most cited articles in TFSC

To understand the most influential research published in *TFSC*, this study examines article citations, which reflect the impact or influence of a publication (Ding and Cronin, 2011). This section answers RQ4 (What are the most influential articles in *TFSC*, and how have they evolved over time?) by classifying all publications included in this journal from 1969 to 2022, i.e., in different decades. Thereafter, the 10 most cited articles in each decade alongside their total number of citations are identified and presented in Table 3. The major topics discussed in these influential publications are then discussed.

4.2.2.1. Decade 1 (1969 to 1978). The first decade concentrates on generic forecasting models. During this decade, the most influential article was cited 691 times. This article is the seventh most cited article in the whole corpus. The article presents a mathematical model that is useful for various types of investigations, such as identifying the beginning of technologically based catastrophes, forecasting technological opportunities, and evaluating the rate of technical change in different cultures (Fisher and Pry, 1971). Three papers published during this decade are based on the Delphi forecasting technique. Turoff (1970), which is the second most cited paper from this decade, suggests ideas for the design of a Delphi study. This study highlights the fact that the Delphi method has been most widely adopted in the area of technological forecasting. Similarly, Dalkey et al. (1970) and Hill and Fowles (1975) highlight the importance of Delphi and explain the reasons for its continuous use despite its shortcomings. Other articles published during this decade highlight important concepts such as technology assessment tools such as interpretive structural modelling (Watson, 1978), the energy substitution model (Marchetti, 1977), the technological substitution model (Nawaz Sharif and Kabir, 1976) and the evolutionary process of technological innovation and productivity improvement (Abernathy and Townsend, 1975).

4.2.2.2. Decade 2 (1979 to 1988). The second decade focuses on sociotechnological concepts. The most frequently cited (164 times) article in

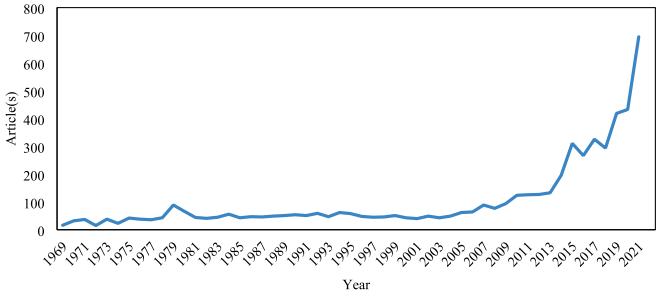


Fig. 4. TFSC's publication trend.

Table 3
Decade-wise analysis of top-cited articles.

Title	Citations
Decade 1 (1969 to 1978)	
A simple substitution model of technological change	693
The design of a policy Delphi	364
The methodological worth of the Delphi forecasting technique	153
Interpretive structural modelling – A useful tool for technology assessment?	133
Technology, productivity and process change	109
A primer for a new cross-impact language – KSIM	106
A generalized model for forecasting technological substitution	92
A mathematical model for trend forecasts	90
Use of self-ratings to improve group estimates: Experimental evaluation of Delphi procedures	85
Primary energy substitution models: On the interaction between energy and society	83
Decade 2 (1979 to 1988)	
Society as a learning system: Discovery, invention, and innovation cycles revisited	165
Stability and agreement criteria for the termination of Delphi studies	161
The perception of technological risks: A literature review	133
The decision Delphi	114
Unlearning and backcasting: Rethinking some of the questions we ask about the future	104
A nonsymmetric responding logistic model for forecasting technological substitution	103
Participants' response to the Delphi method: An attitudinal perspective	93
The structure of man-made organizational crises: Conceptual and empirical issues in the development of a general theory of crisis management	92
Binomial innovation diffusion models with dynamic potential adopter population	91
The multiple perspective concept: With applications to technology assessment and other decision areas	89
Decade 3 (1989 to 1998)	
The adoption of agricultural innovations: A review	511
The past and future of constructive technology assessment	507
Delphi: A re-evaluation of research and theory	405
Theory and applications of the Delphi technique: A bibliography (1975–1994)	325
An evaluation of Delphi	316
The objectives of waste management in India: A futures inquiry	244
Timing, diffusion, and substitution of successive generations of technological innovations: The IBM mainframe case	214
Innovation forecasting	211
Anthropological invariants in travel behaviour	210
Escaping lock-in: The case of the electric vehicle	188
Decade 4 (1999 to 2008)	
Functions of innovation systems: A new approach for analyzing technological change	1343
Scenarios of long-term socio-economic and environmental development under climate stabilization	771
Technology roadmapping – A planning framework for evolution and revolution	755
Forecasting emerging technologies: Use of bibliometrics and patent analysis	706
Current validity of the Delphi method in social sciences	701
Analysis of interactions among the barriers of reverse logistics	626
Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective	482
Climate change impacts on irrigation water requirements: Effects of mitigation, 1990–2080	403
Does social capital determine innovation? To what extent	361
The art of scenarios and strategic planning: Tools and pitfalls	332
Decade 5 (2009 to 2018)	
The future of employment: How susceptible are jobs to computerisation?	1664
Consensus measurement in Delphi studies. Review and implications for future quality assurance	696
Big data analytics: Understanding its capabilities and potential benefits for healthcare organizations	645
Towards an effective framework for building smart cities: Lessons from Seoul and San Francisco	451
Understanding the determinants of RFID adoption in the manufacturing industry	450
Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0	425
Social innovation: Moving the field forward: A conceptual framework	415
From rapid prototyping to home fabrication: How 3D printing is changing business model innovation	396
China's manufacturing locus in 2025: With a comparison of "Made-in-China 2025" and "Industry 4.0"	379
The choice of innovation policy instruments	361
Period 6 (2019 to 2022)	
Green innovation and environmental performance: The role of green transformational leadership and green human resource management	301
Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?	292
Green innovation and organizational performance: The influence of big data and the moderating role of management commitment and HR practices	275
Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective	274
Smart factory performance and Industry 4.0	216
A systematic review of the smart home literature: A user perspective	208
Inequality, ICT and financial access in Africa	208
Can big data and predictive analytics improve social and environmental sustainability?	204
Supply chain re-engineering using blockchain technology: A case of smart contract based tracking process	183
Experimenting for sustainability transitions: A systematic literature review	179

this decade is Marchetti (1980), which focuses on the concept of a learning society as a prominent tool for organizing social behaviour. The article discusses the cyclic trends of inventions and innovation over the past 300 years and explains the link between phasing out new primary energies from the market and these cycles. Linstone (1981) emphasizes the importance of considering the societal and personal perspectives in the context of technology assessments and shows how multiple perspectives help minimize the gap between model and reality to support decision-making. Robinson (1988) analyses trend forecasting methods and argues that inconsistencies in long-term forecasting and modelling in socioeconomic and resource fields are much more than mere technical problems related to forecast accuracy and model validation. These problems have philosophical, political, and methodological roots. The author suggests an integrated rethinking of such forecasting and modelling methods. Covello (1983) reviews social science and behavioural studies, identifies the factors that affect risk perceptions and social conflicts with regard to technological activities and suggests some rational approaches to the task of dealing with technology risks. Similar to the first decade, three highly cited articles in this cluster are based on the Delphi method. Bardecki (1984) discusses the problems of changing attitudes and behaviours during Delphi experiments. The author suggests that the extrapolation of behaviour and cognitive dissonance are useful models for explaining the changes that occur in the responses of participants during different rounds of the Delphi method. Rauch (1979) introduces a new variant of the Delphi method known as Decision Delphi that aims to assist employees in making decisions, while Dajani et al. (1979) analyse the importance of conducting stability tests between successive rounds of Delphi before the analysis of consensus.

4.2.2.3. Decade 3 (1989 to 1998). The highly cited articles published during this decade draw attention to a wide range of topics. The most cited article published during this decade is based on the literature on the adoption of agricultural innovations and concludes that policy interventions can promote technology adoption depending on the nature of policy intervention, type of technology, and market structure in question (Feder and Umali, 1993). Sharma and Gupta (1995) examine

the objectives of waste management in India and analyse the relationships among those objectives using interpretive structural modelling, whereas Marchetti (1994) enquires into the basic instincts underlying travellers' behaviour and demonstrates the interconnection between technological progress and economic constraints. Three highly cited studies published during this decade discuss the applications of the Delphi method. Gupta and Clarke (1996) review the literature on the applications of the Delphi method over a period of 20 years and conclude that Delphi is widely used in a diverse range of domains. Delphi publications over the past three decades indicate that the scientific community is continually interested in this methodology. Rowe et al. (1991) and Woudenberg (1991) critically examine the Delphi technique and examine the inadequacies of this process. The other highly cited articles published during this decade focus on technology and innovation. Mahajan and Muller (1996) investigate the problem of determining the optimal timing for introducing new technology to the market in such a way as to avoid affecting the sales of current generation technology. The author develops a model that captures both the substitution and adoption patterns of each successive generation of technology innovation. The study concludes that a firm should either introduce a new generation technology immediately after it becomes available or delay its introduction until the mature stage in the life-cycle of the current generation. Schot and Rip (1997) analyse the constructive technology assessment (CTA) approach, which focuses on the development and implementation of new technologies. The article discusses how CTA evolved over past decades as well as the future of this approach.

4.2.2.4. Decade 4 (1999 to 2008). The research focus of the authors of highly cited articles published during this decade is primarily on innovative technologies, social technical systems, and climatic issues. The most cited article published during this decade, which is also the second most-cited article since the inception of *TFSC*, is based on the functions of innovative systems and describes the impact of innovation systems on technology change (Hekkert et al., 2007). Geels (2005) explores system innovations, investigates transitions in societal functions such as transport, housing, and communication, and demonstrates how transitions in sociotechnical systems result from the interplay between society and technology. Landry et al. (2002) investigate the relationship between social capital and innovation, and they provide strong evidence that different forms of social capital determine innovation in manufacturing firms. Daim et al. (2006) focus on the need to create integrated tools for technology forecasting and show that the integration and use of multiple methodologies such as bibliometrics and patent analysis can improve the results of technology forecasting. Riahi et al. (2007) discuss both socioeconomic and environmental development issues and propose that technology roadmapping enables organizations to scan the environment and helps them track the performance of individuals as well as potential disruptive technologies that can eventually help companies survive in turbulent environments. Fischer et al. (2007) investigate the demand for agricultural water in the context of a new socioeconomic scenario and identify future irrigation water requirements based on climate change and projected irrigated land.

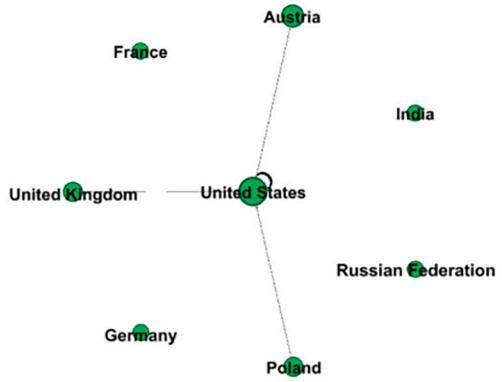
4.2.2.5. Decade 5 (2009 to 2018). The highly cited articles published during this decade predominantly focus on the innovative technologies associated with Industry 4.0 and their implications for businesses. Müller et al. (2018) analyse the ways in which Industry 4.0 has changed the business models of SMEs through smart manufacturing, the digitization of processes, and intercompany connectivity. Wang et al. (2010) emphasize the importance of RFID adoption in the manufacturing industry with the aim of improving process efficiency by increasing supply chain visibility. These authors identify nine variables that help predict the adoption of RFID in the manufacturing industry. Rayna and Striukova (2016) highlight the usage of 3D printing, which is another prominent technology associated with Industry 4.0. The study examines different adoption phases of 3D printing and investigates the impact of each phase on business model innovation. Li (2018) compares "Industry 4.0" in Germany with "Made in China 2025" in China. This study analyses data drawn from China's National Bureau of Statistics and the World Bank and concludes that China is improving its manufacturing capability and technological entrepreneurship, which ultimately entails socioeconomic changes for the country. Wang et al. (2018) discuss the potential benefits of big data analytics in the health care industry and highlight five big data analytics capabilities, including unstructured data analytical capability, analytical capability for patterns of care, predictive capability, decision support capability, and traceability. Other prominent studies published during this period shed light on the impact of computerization on jobs in US labour markets (Frey and Osborne, 2017), identify social innovation as a driver of social change (Cajaiba-Santana, 2014), and develop a dynamic innovative platform that is responsible for coordinating activities in the private and public sectors related to the construction of smart cities (Lee et al., 2014).

4.2.2.6. Period 6 (2019 to 2022). This period includes the most highly cited articles published in *TFSC*. Unlike previous decades, this period contains only articles published during the past four years. The main focus of the highly cited articles published during this period is on contemporary trends in business, such as green innovation, Industry 4.0, and sustainability. Green innovations are becoming increasingly popular among academics and practitioners. Singh et al. (2020a, 2020b) analyse the role of green human resource management in promoting green innovation among firms and its impact on improving firms' environmental performance. Similarly, El-Kassar and Singh (2019) examine the relationships between green innovation and its drivers. The authors assess the impact of green innovation on organizational performance and emphasize the importance of adapting and adopting environmentally friendly business activities. The second notable topic discussed during this period is Industry 4.0. The highly cited articles published during this period discuss the ways in which Industry 4.0 has transformed business models and improved efficiency. Frank et al. (2019) discuss how a combination of Industry 4.0 with servitization transforms business operations and adds value for customers. The types of technology associated with Industry 4.0 play a crucial role in improving the performance of organizations. The analysis conducted by Büchi et al. (2020) explains that the availability of the variety of innovative technologies associated with Industry 4.0 helps firms improve their performance. Horváth and Szabó (2019) elucidate the drivers of and barriers to the implementation of Industry 4.0 technologies in organizations, and Chang et al. (2019) explain the role of blockchain technologies in disintermediating business processes and facilitating the tracking of information and the promotion of collaboration among supply chain members. Finally, the remaining highly cited articles published during this period focus on the concept of sustainable practices in business. These articles shed light on the impact of information communication technology on reducing income inequality (Tchamyou et al., 2019) and the role of big data and predictive analysis in improving the environmental performance and social performance of firms (Dubey et al., 2019).

4.2.3. TFSC's global outreach

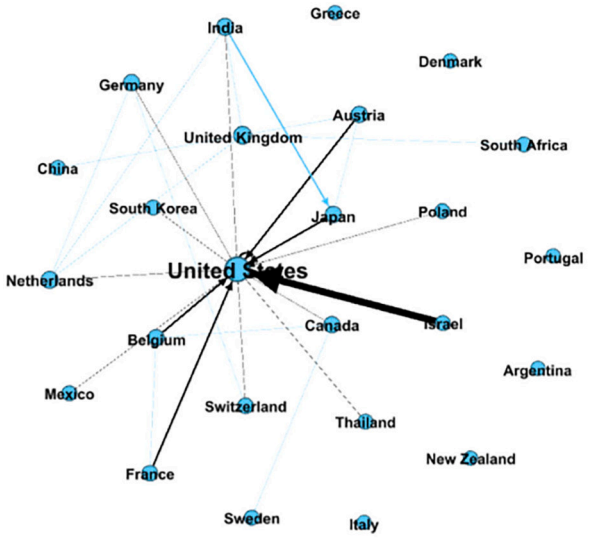
This section discusses the global outreach of *TFSC* from the historical moment of the moon landing in 1969 until the recent establishment of the metaverse in 2022 with the aim of answering RQ5 (What is the geographical dispersion of the authors published in TFSC, and how has this dispersion evolved over time?

The country-level collaboration network of the authors published in *TFSC* for the six subperiods is shown in Fig. 5. This figure highlights the collaborations among prominent authors from different countries, which reflect the international diversity and inclusivity of *TFSC*.

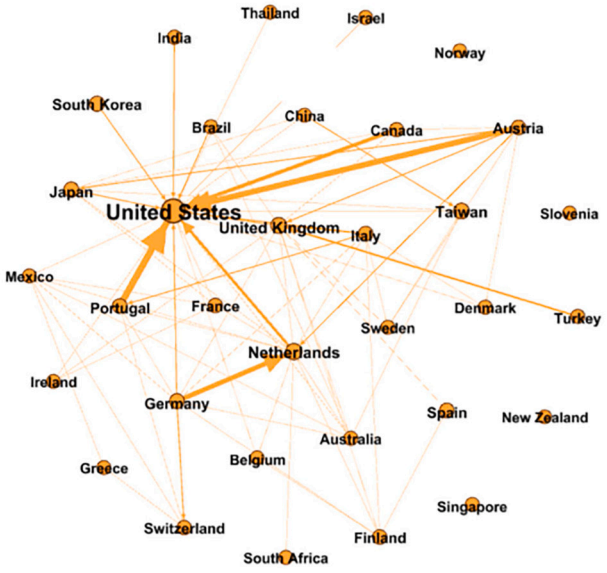


Panel A. 1969–1978

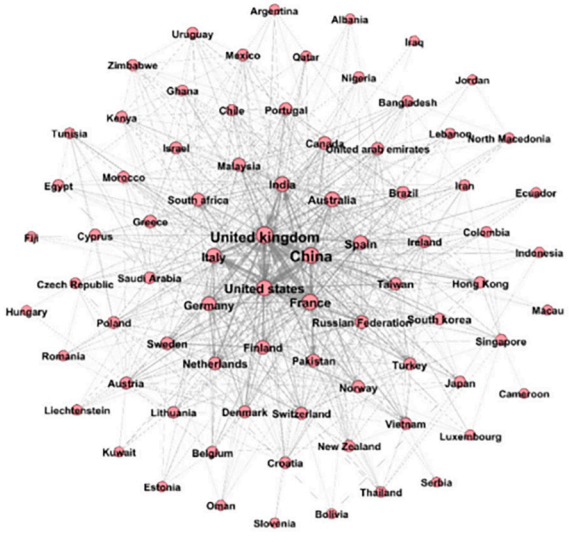
Panel B. 1979–1988



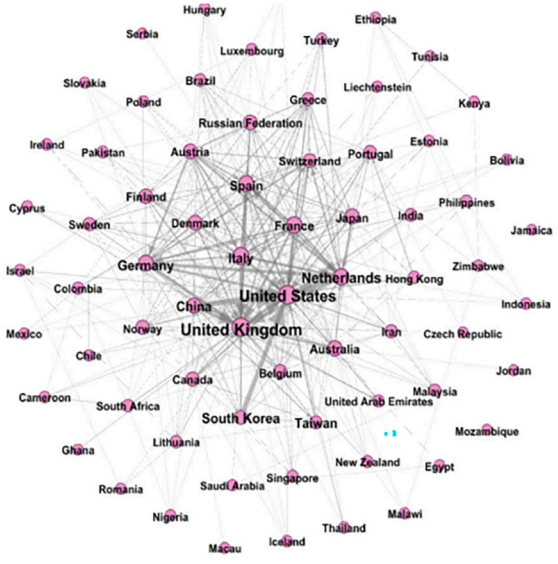
Panel C. 1989–1998



Panel D. 1999–2008



Panel E. 2009–2018



Panel F. 2019–2022

(caption on next page)

Fig. 5. *TFSC*'s country collaboration network between 1969 and 2022.
Notes: The collaboration network is based on author affiliations. When the authors from those countries co-author an article, a link is formed between two countries. The node's size is determined by the number of other nodes forming a connection with a given country node. The link's thickness between two nodes depends on number of times authors from countries they represent published in *TFSC*. Unconnected nodes indicate that authors from those countries did not co-author a *TFSC* article with authors from any other countries during the given period.

Notably, each panel in this figure represents the collaboration network associated with a particular subperiod. The nodes in the network diagram represent the countries affiliated with the authors published in *TFSC*. When authors from two countries work collaboratively, a link is established between their countries. An unconnected node represents a country for which the corresponding author has not coauthored an article in *TFSC* with an author in another country. The network diagram in each panel illustrates the collaboration among authors from different countries and demonstrates how intercountry author collaboration globalizes the research in *TFSC*.

The collaborative network of authors published in *TFSC* between 1969 and 1978 is presented in Panel A of Fig. 5, indicating that the country collaboration network of the journal during this period was concentrated in the United States, United Kingdom, Austria, and Poland. In addition, there are four unconnected nodes in this network that represent France, Germany, India, and the Russian Federation.

The collaborative network of the authors affiliated with *TFSC* between 1979 and 1988 is presented in Panel B of Fig. 5, indicating that the country collaboration network expanded during this decade, publishing authors from more countries, particularly the United States, Canada, the United Kingdom, Japan, Israel, and the Netherlands. The link between the countries in the network diagram is very thin, implying that the collaboration among authors from the countries included in this network is not very strong.

The collaborative network of authors affiliated with *TFSC* between 1989 and 1998 is presented in Panel C of Fig. 5. The diagram shows that the collaborative network expanded further during this period, indicating stronger links among countries. This thickest line in the diagram is between the United States and Israel, which indicates coauthors from these countries exhibited the strongest collaboration. As in the first two decades, the United States is the most prominent country in the network, exhibiting strong connections with France, Belgium, Austria, and Japan. The expanding collaboration network of the journal shows that over time, the journal became more global.

The collaborative network of authors affiliated with *TFSC* between 1999 and 2008 continued to expand, as indicated in Panel D of Fig. 5. The United States remains the most prominent country in the collaboration network, exhibiting the maximum number of links with other countries. Portugal, which was an unconnected node during the previous period, exhibits a strong connection with the United States. Other countries with strong links with the United States include Canada, Austria, the Netherlands, and the United Kingdom. The link between Germany and the Netherlands also became stronger than it was during the previous period, thus indicating an increase in the number of collaborations among authors from these two countries during this period.

The collaborative network of authors affiliated with *TFSC* between 2009 and 2018 is depicted in Panel E of Fig. 5. This network is very diverse and includes 70 countries, thus highlighting the consistent efforts of the journal to become a global platform in which researchers from all countries can publish quality research on the methodology and practice of technological forecasting. The most prominent country in this network is the United Kingdom, which exhibits close coauthorship ties with Italy, China, and Germany.

The collaborative network of authors affiliated with *TFSC* between 2019 and 2022 is portrayed in Panel F of Fig. 5. Unlike the previous five periods, this period covers only four years. However, the network diagram shows that this period features the largest and densest collaboration network, including the highest number of countries. The diagram shows that the journal has consistently increased its global presence based on collaborations, connecting authors from a diverse range of countries. The United Kingdom remains the most prominent country in this network, exhibiting the highest number of links with other countries, followed by France, China, and the United States. The United Kingdom exhibits strong connections with China, the United States, and Italy, as indicated by the thickness of the lines among these nodes in the network diagram.

Overall, it is clear that *TFSC* has increased its global presence substantially since its inception in 1969, making it a truly diverse and inclusive international journal.

5. Discussion

5.1. Key takeaways and the theoretical implications of the STM results

STM-based approaches are used to extract key latent topics from a textual corpus and to provide a topic-based summary. In this regard, the entire collection of text documents can be represented as a probabilistic mixture of topics. The proportion of each topic in the entire text collection is known as probabilistic topic prevalence, which is depicted in Fig. 6, indicating that the footprint of technological forecasting and futures studies covers 18 topics; Topic 1 (i.e., technology assessment and society) and Topic 3 (i.e., classification and forecasting models) are the most prominent topics, accounting for more than 17 % of the extant research published in *TFSC*.

Taken collectively, the STM results highlight the *diversity of topical coverage in technological forecasting and futures studies*. Notably, the topical coverage indicates that *technology is both a trend that deserves scrutiny* (such as in the cases of automation, the digital workplace, and AI) *and a tool to be leveraged to generate knowledge* (such as in the cases of scenario planning and technology forecasting). Moreover, the scope of *topics at the intersection of technology and futures studies is multifaceted* and can be viewed from a *multilevel perspective* (e.g., at the macro level in terms of technology assessment and society or at the micro level in terms of technology roadmapping via patent analysis) or a *multistakeholder standpoint* (e.g., in terms of governments' innovation investments and subsidies, organizations' ambidexterity and dynamic capabilities, and consumers' behaviour on social media and in online environments), thereby *highlighting both the scope of possible study and the need to clearly delineate the unit of analysis and the relationships under study*. These insights are important from a *theoretical perspective,* as the *nomological network of prominent topics represents the major streams of research on which prospective authors can focus by locating relevant gaps and positioning their contributions accordingly* (Kraus et al., 2022b; Lim et al., 2022b; Mukherjee et al., 2022). By extension, the insights generated by this research can also serve as *a basis to support claims regarding whether a topic is emerging or established*. Indeed, it is possible for new topics to emerge and establish themselves in the future, especially topics whose evolution remains less understood, for example, generative artificial intelligence technologies such as ChatGPT (e.g., how it has evolved from conversational agents and how it can coexist with people and other technologies in the future) and metaverse-related technologies such as Decentraland and Sandbox (e.g., how such technology has evolved from the internet and virtual reality and how it can coexist with the physical world in the future); we strongly encourage and call upon future researchers to explore and investigate these topics.

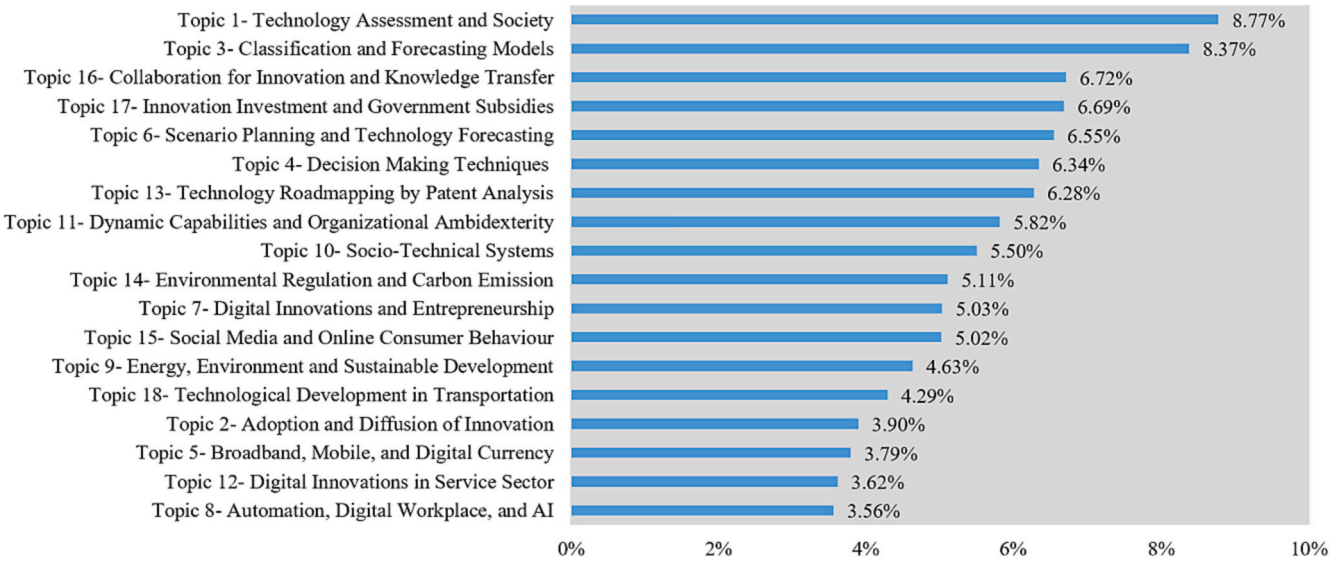


Fig. 6. Extracted topics and their probabilistic proportions.
Notes: Only short forms of topic labels are used due to visualization limitation. The complete topic labels are available in Table 2.
Notes: The threshold value for correlation is set as 0.1 to map the network. Nodes with less than 0.1 correlation are not displayed. Only short forms of topic labels are used due to visualization limitation. The complete topic labels are available in Table 2.

5.2. Key takeaways and managerial implications of the results of the bibliometric analysis

Bibliometric analysis offers information regarding the publication trends (i.e., productivity), noteworthy citations (i.e., impact or influence), and international scope (i.e., outreach) of articles published in *TFSC*. Since the inception of the journal, the number of published articles has consistently increased, *indicating both research interest in and the productivity of technological forecasting and futures studies*. The 10 most cited articles from each decade between 1969 and 2022 *reaffirm the relevance of TFSC as an authoritative source for insights into technological forecasting and futures studies* and reveal *a range of distinctive topics*. In this context, the period from 1969 to 1978 is characterized by generic forecasting, the period from 1979 to 1988 focuses on sociotechnological concepts, the period from 1989 to 1998 is diversified in terms of its topical coverage of technological innovations (e.g., agriculture, transportation, travel, waste), the period from 1999 to 2008 is dedicated to innovative technologies, social technical systems, and climatic issues, the period from 2009 to 2018 is focused on the innovative technologies associated with Industry 4.0 and their implications for businesses, and the most recent period from 2019 to 2022 emphasizes contemporary trends in business such as green innovation, Industry 4.0, and sustainability. Finally, the geographical dispersion of the authors and the evolution of that dispersion over time provide clear evidence of the *internationalization of technological forecasting and futures studies* and, by extension, the *diversity and inclusivity of the research published in TFSC*. These insights are important from a *managerial standpoint,* as they facilitate *an objective assessment of the productivity, impact or influence, and outreach (diversity, inclusivity) of technological forecasting and futures studies* (Kraus et al., 2022b; Lim et al., 2022b; Mukherjee et al., 2022).

6. Conclusion

The present study maps the topical structure of *TFSC* by identifying the most prominent topics using a machine learning-based STM alongside bibliometric analysis. The insights and implications generated by this study can be summarized as follows.

First, the STM identifies 18 prominent topics that have dominated the literature published in *TFSC* for more than 50 years, ranging from the moon landing in 1969 to the metaverse in 2022. The topics thus identified have the virtue of being comparatively objective, as they were generated by the STM algorithm without any human intervention. The results also provide the top 10 words sorted by probability and FREX score for each identified topic. Further analysis of the topics indicates increasing scholarly interest in Topic 5 (broadband, mobile, and digital currency), Topic 11 (dynamic capabilities, organizational ambidexterity, innovation, and firm performance), Topic 12 (digital innovations in the service sector – health care, banking, and tourism), Topic 16 (collaboration for innovation and knowledge transfer), and Topic 17 (innovation investment, funding, R&D expenditures, and government subsidies). The semantic coherence and topic exclusivity scores of the topics also indicate that all topics are semantically distinct and fairly separated. Additionally, the topic correlation matrix indicates that all correlation values are less than 0.2, thus indicating that the underlying terms that form the content of these topics are not identical and thereby verifying the accuracy of the topic modelling results.

From a *theoretical perspective*, the meaningful insights regarding the topical trends highlight the frontiers of future research in *TFSC* because such multidimensional knowledge can be used to guide future research endeavours that can have deep impacts on society. The results reaffirm the claim that the conceptual research landscape of *TFSC* evolved significantly between 1969 and 2022; thus, some topics have evidently matured and now offer very limited opportunities for further exploration. However, several topics have obviously emerged as hotspots in recent years, which is indicative of their greater popularity and intellectual significance among contemporary scholars. These insights can potentially help the research community target topics that offer more paths towards future scholarly significance and impact. Furthermore, the editorial team of *TFSC* can plan special issues to encourage greater intellectual exploration of topics that exhibit a trend towards increasing attention or topics that may be trending in practice but less understood in terms of theory due to the lack of a major stream of research on such topics in the field (e.g., generative artificial intelligence technologies such as ChatGPT or metaverse-related technologies such as Decentraland and Sandbox).

Furthermore, the study reports the results of a bibliometric analysis on the articles published in *TFSC* and the countries with which the authors of those articles are affiliated. Notably, the study uses a citation analysis to identify the top 10 most-cited articles for each decade/period and uses a content analysis of these articles to highlight the different

topics they discuss. The study also analyses the decade-by-decade geographical dispersion of the authors published in *TFSC* and presents the country-level collaboration network of authors affiliated with *TFSC* for the six subperiods. The network diagrams for each subperiod show that the intercountry collaborations among authors increase over time, thus indicating the internationalization of the journal.

From a *managerial perspective*, the study offers guidance to managers and policy-makers regarding major technological trends and their impacts on society, thus helping them remain of about the needs of society and enabling them to make informed decisions regarding the rollout of the latest technologies. The study also supports decision-making on the part of journal editors and scholars by empowering them with insights that can help them identify the functional departments or major streams of technological forecasting and futures studies as well as to respond to the trending needs of the field by producing and publishing additional timely and relevant research.

With regard to the future, *TFSC* remains in a good position with regard to shaping the narrative of technological forecasting and its impact on society and the environment. The strategy of asking expert and seasoned scholars to guest edit special issues for the journal is profound and should continue to be employed in the future. Such special issues can focus on topics associated with increasing scholarly interest, such as broadband, mobile, and digital currency (Topic 5); dynamic capabilities, organizational ambidexterity, innovation, and firm performance (Topic 11); digital innovations in the service sector (health care, banking, and tourism) (Topic 12); collaboration for innovation and knowledge transfer (Topic 16); and innovation investment, funding, R&D expenditures, and government subsidies (Topic 17). Beyond this focus on existing topics, the journal is also in a good position to inspire new research of global importance, which may include but is not limited to technological forecasting and preparedness for the aging population (Lim and Bowman, 2022), planetary health (Lim, 2022a), the future of work (Bamel et al., 2022), and the new normal (Lim, 2022b) as well as defences against mega crises or disruptions such as the COVID-19 pandemic (Lim, 2021) and the Ukraine-Russia conflict (Lim et al., 2022a). Finally, future reviews of the literature published in *TFSC*, if any such research is conducted, could investigate the theories, contexts, and methodologies (Kraus et al., 2022b; Lim et al., 2022b) underlying technological forecasting and futures studies, thereby building on the insights generated by the present review as well as previous reviews of the journal.

CRediT authorship contribution statement

Sascha Kraus: Conceptualization, Investigation, Project Administration, Supervision, Writing – Review & Editing; **Satish Kumar:** Conceptualization, Investigation, Methodology, Supervision, Writing – Review & Editing; **Weng Marc Lim:** Conceptualization, Investigation, Methodology, Supervision, Visualization, Writing – Original Draft, Review & Editing; **Jaspreet Kaur:** Investigation, Formal analysis, Visualization, Writing – Original Draft; **Anuj Sharma:** Investigation, Formal analysis, Visualization, Writing – Original Draft; **Francesco Schiavone:** Investigation, Methodology, Writing – Review & Editing.

Data availability

No data was used for the research described in the article.

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