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Knowledge creation dynamics of technological forecasting and social change special issues

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ABSTRACT

Technological Forecasting and Social Change (*TFSC*) is a leading peer-reviewed journal that addresses issues at the intersection of technology and society. A major strategy of the journal is to actively solicit and publish Special Issues (SIs). These SIs were first launched in 1979 to highlight and solicit manuscripts from the "hot" emerging issues of the discipline. This paper aims to analyze SIs and to highlight it's impact on TFSC as compared to Regular Issues (RIs). Using bibliometric analysis, this study first establishes that SIs have a higher impact on the field than RIs when evaluated based on average citations per manuscript, percentage of 'hot' papers, and the rate of citations per annum. The study then identifies leading actors (authors, affiliated institutions, and countries) and journals (knowledge inflow/outflow) that have contributed to the success of TFSC-SIs. Finally, using bibliographic coupling, seven thematic clusters of TFSC's SIs were identified. These clusters were compared with the knowledge clusters developed by Singh et al. (2020) for the entirety of TFSC journals, and four clusters unique to SIs were identified i.e. (Climate Change & Energy, Entrepreneurship and Innovation, Sustainability and, Social Media & Internet of Things). It is observed that these unique SI clusters have received disproportionate attention during the last decade and are likely to influence the future trajectory of the journal.

1. Introduction

Technological Forecasting and Social Change (*TFSC*) recently celebrated its 50th anniversary with a series of introspective reviews about its intellectual structure and contributions to the field (Mas-Tur et al., 2021; Sarin et al., 2020; Singh et al., 2020). These studies provided a comprehensive overview of its important actors (authors, universities, journals, and countries) and scientific contributions (most cited papers and thematic clusters) of the journal over its five decades of history (1969–2019). Since its inception, the journal has been progressing and is currently ranked as one of the top-rated journals in the discipline. According to Academic Journal Guide (AJG, 2018) and the latest Australian Business Deans Council (ABDC, 2019), TFSC is ranked at "3″ and "A" categories, respectively. Further, as per JCR (Journal Citation Report-2020), *TFSC* is ranked 17th out of 152 business journals with an impact factor of 5.846. (SCImago 2019) lists it in the first quartile of journals with a rank of 22nd out of 241 journals in Business, Management, and Accounting (Management of Technology and Innovation) and at 22nd out of 237 journals in Psychology (Applied Psychology). Likewise, TFSC is ranked 6th as per Google Scholar (2019) in Business, Economics, and Management (Strategic Management) categories with an h5-index of 87. All these rankings attest to the progress that the journal has achieved in the five decades of its existence.

This paper supplements earlier bibliometric studies that had reviewed the progress of TFSC over its five decades of existence (Mas-Tur et al., 2021; Sarin et al., 2020; Singh et al., 2020). However, it differs from them in that it exclusively focuses on the importance of Special Issues (SIs) of TFSC. TFSC published its first Regular Issue (RI) in 1969 while it published its first SI a decade later in 1979. SIs differ from RIs as they explicitly focus on emerging topics of interest to the journal. It

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solicits manuscripts within a pre-defined theme rather than any topic which falls within the ambit of the aims and scope of the journal. Some journals and editors remain suspicious of the real impact that these SIs have over RI publications and tend to avoid them (Conlon et al., 2006). However, others consider it an important tool to strengthen a journal's linkage with an emerging "hot" area of interest by explicitly welcoming authors working in that domain to send their manuscripts for publication.

For TFSC, these SIs hold significant importance as it has regularly published them for nearly four decades (see Fig. 1) and currently lists more than 50 SI calls for publication on its website. In addition, TFSC's SIs also represent a significant part of the journal's history as it represents 30% (1309/4356) of the total publications and 37% (40,768/111,618) of the total citations received by the journal over its five decades of existence. Phillips (2014) acknowledges the importance of SIs in his editorial as they generate more interest from readers and bring above-average citations. However, to date no systematic study has been conducted that explicitly examines the dynamics of TFSC's SIs (1979–2019) and provides a comparison with RIs (1969–2019).

Following bibliographic traditions, this manuscript addresses this gap by providing a comprehensive overview of the knowledge creation dynamics of TFSC's SIs. In the following sections, we first address whether TFSC's SIs have contributed positively to the development of TFSC or not. Subsequently, the bibliometric methodology and data collection procedures are discussed. After this, the study highlights the top contributors (manuscripts, authors, institutes/centers of excellence, countries) and journals that regularly publish and cite TFSC's SIs. In the end, using bibliographic coupling, the study identifies seven thematic clusters of TFSC's SIs along with prominent subthemes and the most important contributors (manuscripts, authors, institutes, and countries) for each cluster. These thematic clusters are also compared with general knowledge clusters of TFSC, as proposed by Singh et al. (2020), to identify unique SI clusters along with their publication trajectories.

1.1. Are TFSC's SIs really special?

TFSC published its first SI in 1979 with eight manuscripts and, since then it has grown consistently with 213 SI manuscripts published in 2019 only (see Appendix A). Their importance to TFSC is highlighted by the fact that the journal's Elsevier website carries a dedicated section for SIs and lists more than 50 calls for papers. Since 2019, the journal has further cemented the role of SIs by concurrently and regularly publishing both RI and SI articles within every volume.

Between 1979 and 2019, TFSC published 1309 SI articles, receiving 40,768 citations at an average of 31.14 citations per publication (see Table 1). In comparison, TFSC published 3047 regular manuscripts that received 70,850 citations at an average of 23.25 citations per manuscript. This shows that SI articles receive 34% more citations than RI articles. Results of the non-parametric Mann-Whitney U Test confirm that the citation patterns of SIs and RIs are statistically different ($p < .001$). Phillips (2014) elaborates that although SIs are given a lower weight than RI manuscripts in promotion, the citation patterns of TFSC's SIs demonstrate that these manuscripts are more impactful than RI manuscripts, thus meriting equal consideration, if not more, by the promotional committees.

Table 1 demonstrates that RIs have a higher 'h' and 'g' index than SI (see Table 1), an indication of its ability to have higher number of 'Hot Papers'. However, studies demonstrate that, in absolute term, both 'h' and 'g' indices are positively correlated with the number of publications (Costas et al. 2008; Egghe, 2006; Van Raan, 2006). Therefore, a direct comparison of SI with RI is likely going to bias assessment as the former represent less than half of RI manuscripts. To address this, we compare

Table 1
Overview of TFSC's special versus regular issues: A comparison.

	Special Issue	Regular Issue
Timespan	**1979–2019**	**1969–2019**
Panel A. Descriptive statistics		
Total publications (TP)	1309	3047
Total cited publications (TCP)	1267	2832
Index (TCP/TP)	97%	93%
Total citations (TC)	40,768	70,850
Average citations (C/P)	31.14	23.25
Citations per cited publication (C/CP)	32.18	25.02
h-index	89	101
g-index	140	154
Number of active years (NAY)	32	51
Productivity per active year (PAY)	40.91	59.75
Number of authors' affiliating countries (NAAC)	66	75
Panel B. Co-authorship information		
Number of contributing authors (NCA)	3652	6775
Number of affiliated authors (excludes repetitions) (NAA)	2817	4848
Authors of single-authored documents (ASA)	253	749
Authors of co-authored documents (ACA)	2564	4099
Single-authored documents (SA)	280	1129
Co-authored documents (CA)	1029	1918
Collaboration index (CI)	2.49	2.14
Panel C. Document type		
Article	1301	3043
Review	8	4

Note: This table compares the descriptive indicators of special versus regular issues of TFSC published between 1969 and 2019.

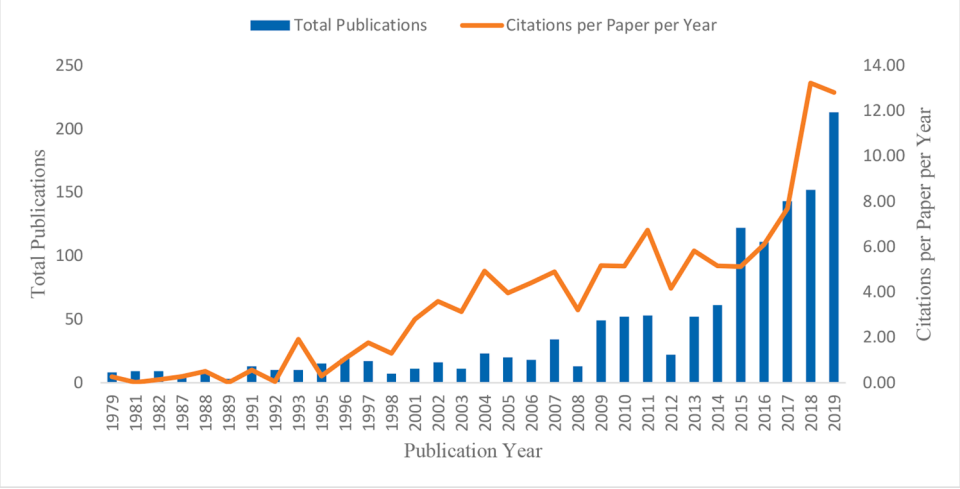

Fig. 1. Annual publications of TFSC-SIs.

the performance of SI vs. RI as a percentage of total publications using 'h' and 'g' index benchmarks. For example, assuming higher 'h' index of RI (101) as a benchmark, we examine what percentage of RI vs SI publications meet this standard. Data shows that there are 101 RI and 72 SI manuscripts with 101 or more citations. In percentage terms, it represents that nearly 3.31% (101/3047) of RI manuscripts and 5.50% (72/1309) of SI manuscripts meet this benchmark. Similarly, 'g' index, which is a rank ordered evaluation of the most citated 'hot' manuscripts of a journal, demonstrates that although SI represent 43% of the RI papers (1309/3047) but its g-index represents 91% of RI's g-index (140/154). Thus, in absolute terms RI has more 'hot papers' than SI, but relative to the total numbers of paper published manuscripts, SI demonstrates significantly higher percentage of 'hot papers'.

Another perspective that merits consideration is that as SIs usually address current topics of interest, then do they accumulate citations at a faster rate than RIs? To examine this premise, a regression model was estimated for both SIs and RIs with the calendar year as an independent factor and the annual citations for that specific year as the dependent factor. A significant relationship was observed between year and annual citations for both RI ($F(1, 49) = 101.56$, $p < 0.01$) and SI ($F(1, 39) = 96.72$, $p < .01$) such that 'year' predicts 68% of variance in annual citations for RI and 71% variance for SI. Results demonstrate that for RI, the total citations increase by 70.14 for every year, while it increases by 85.22 for SIs. This demonstrates that for each additional year, the SIs accumulate nearly 20% higher annual citations than RI, hence supporting the assertation that SIs accumulate citations at a higher rate than RIs.

2. Methodology

To present an overview of TFSC's SIs knowledge structure, this study uses bibliometric analysis as it provides a systematic overview of the articles within a domain of interest (Aria and Cuccurullo, 2017; Khan et al., 2021). The earliest roots of this technique were somehow available in different forms (Broadus, 1987), but it was Pritchard (1969) who formally introduced the term which has since then gained popularity in fields such as management (Podsakoff et al., 2008), economics (Bonilla et al., 2015), arts-based management (Ferreira, 2018), manufacturing (Caviggioli and Ughetto, 2019), and marketing (Khan et al., 2020).

Bibliometric review differs from other established review methods such as meta-analysis and systematic reviews, in that it focuses on identifying knowledge structures and trends of a specific field of interest (Donthu et al., 2021) by processing large volumes of quantitative bibliometric data (publications and citations). Ellegaard and Wallin (2015) discussed that researchers use this technique to study the repository of literature using quantitative metrics (citation counts, h-index, citations per cited paper, and annual citations per cited paper—see Appendix B for definitions) for bibliographic materials (articles, books, review papers, and proceedings). On the other hand, meta-analysis focuses on the relationships between variables and, while using quantitative data, it focuses on estimating the relative effect sizes and directionality of the variable relationships under study. Finally, systematic reviews differ from both bibliometrics and meta-analysis in that they are qualitative reviews where the focus is to systematically synthesize a narrow domain of research into an integrated conceptual framework with directions for future research (Palmatier,Houstan and Hulland, 2018). Donthu et al. (2021) while comparing these review methods, argue that these methods remain complementary to each other with the choice of method being dictated by the underlying aim of the study (knowledge structural analysis vs. relationship analysis vs. conceptual review), volume of data being processed (large vs. small) and the type of analysis (quantitative vs. qualitative). As the focus of this study remains on examining the knowledge structures of TFSC-SIs using a relatively large volume of publications (i.e., 1309), thus bibliometric review remains the relevant procedure for this study.

Bibliometric analysis is a powerful technique for characterizing, evaluating, and tracing published research in journals or a domain of research (Dana et al., 2021; Kumar et al., 2020; Merigó et al., 2019; Sureka et al., 2020; Wang et al., 2019). This study uses bibliometrics to highlight the most important manuscripts, authors, institutes (centers of excellences), countries, and journals for TFSC's SIs. Moreover, to identify thematic clusters of TFSC's SIs, this study uses bibliographic coupling. It measures "relatedness" between two articles based on the commonalities that exist in their bibliographies (Kessler (1963). For example, two manuscripts are considered to be bibliographically coupled when they share at least one common reference source in their bibliographies (article "A" cited by both articles "B" and "C"). The strength of bibliographic couple depends on the number of common references that exist between articles (Egghe and Rousseau, 2002). Articles that strongly relate to each other are then clustered together to identify a common theme between them. To further report within-cluster knowledge dynamics, this study also presents a network map of keywords for each cluster based on the author-provided keywords and demonstrate how their importance have evolved over the last two decades.

For this study, the data is sourced from Scopus on the 4th January 2021. The database remains a commonly used source for bibliometric studies (Archambault et al., 2009; Baas et al., 2020; Darmadji et al., 2018). Articles were only considered till 2019, as they remained the most recent year for which full citation data was available, i.e., a minimum of two years post publication (2019 and 2020).

3. Results

3.1. Top 25 of TFSC's SI

In this section, we highlight the top 25 contributors (manuscripts, authors, author-affiliated universities, and countries) of TFSC's SIs, along with the relevant metrics.[1]

3.1.1. Manuscripts

Citations of an article demonstrate its impact on the field (Svensson, 2010). TFSC's SIs' top 25 articles represent only 1.9% (25 of 1309) of the total SI articles, but they account for 19.26% of total SI citations (7854 of total 40,768). This highlights the disproportionate influence that these articles have on the field. These top 25 articles cover a wide range of topics such as climate change; big data analytics, disruptive technologies, sustainability, and social and technological innovation (see Table 2).

Riahi et al. (2007) presented a study titled "*Scenarios of long-term socioeconomic and environmental development under climate stabilization*" that ranked first with the highest number of citations (TC: 665). Their paper first discusses Greenhouse Gas (GHG) emissions and socioeconomic development according to Article 2 of the United Nations Framework Convention on Climate Change. Then, by using Integrated Assessment Modeling Framework (IIASA), the authors demonstrated energy sector to be the main source of GHG emissions and emphasized on its complete restructuring. The second highest cited paper (TC: 646) was by Phaal et al. (2004) titled "*Technology roadmapping—A planning framework for evolution and revolution*". It reviewed the technology and knowledge management issues using two perspectives, company and multinational perspectives. The third most cited article was (TC: 588) by Daim et al. (2006) on "*Forecasting emerging technologies: use of bibliometrics and patent analysis*". They discussed the difficulties in forecasting emerging technologies due to the unavailability of historical data and, suggested the use of bibliometrics, patent analysis, and system dynamics as a way forward. Other notable manuscripts, in terms of Citations per Year (C/Y), are Wang et al. (2018); Li (2018), and Rayna and Striukova

[1] For the interest of brevity, only statistics of common interest are reported. Detailed statistical information is available form authors upon request.

Table 2
The most cited articles published in TFSC-SIs from 1979 to 2019.

R	Title	Author(s)	Year	TC	C/Y	R (C/Y)
1	Scenarios of Long-Term Socio-Economic and Environmental Development Under Climate Stabilization	Riahi K; Grübler A; Nakicenovic N	2007	665	51.15	6
2	Technology Roadmapping - A Planning Framework for Evolution and Revolution	Phaal R; Farrukh CJP; Probert DR..	2004	646	40.38	8
3	Forecasting Emerging Technologies: Use of Bibliometrics And Patent Analysis	Daim Tu; Rueda G; Martin H; Gerdsri P	2006	588	42.00	7
4	The Past and Future of Constructive Technology Assessment	Schot J; Rip A	1997	453	19.70	16
5	The adoption of agricultural innovations: A review	Feder G; Umali Dl	1993	451	16.70	20
6	Processes and Patterns in Transitions and System Innovations: Refining the Co-Evolutionary Multi-Level Perspective	Geels FW	2005	400	26.67	10
7	Big Data Analytics: Understanding Its Capabilities and Potential Benefits for Healthcare Organizations	Wang Y; Kung L; Byrd TA	2018	346	173.00	1
8	Climate Change Impacts on Irrigation Water Requirements: Effects of Mitigation, 1990–2080	Fischer G;T ubiello FN; Van Velthuizen H; Wiberg DQ	2007	340	26.15	11
9	Towards an Effective Framework for Building Smart Cities: Lessons from Seoul And San Francisco	Lee JH; Hancock Mg; Hu M-C	2014	327	54.50	5
10	Does social capital determine innovation? To what extent	Landry R; Amara N; Lamari M	2002	309	17.17	19
11	From Rapid Prototyping to Home Fabrication: How 3d Printing Is Changing Business Model Innovation	Rayna T; Striukova L	2016	276	69.00	3
12	Enhancing Rigour in the Delphi Technique Research	Hasson F; Keeney S	2011	257	28.56	9
13	Intellectual Capital and New Product Development Performance: The Mediating Role of Organizational Learning Capability	Hsu Y-H; Fang W	2009	251	22.82	13
14	The Cost of Additive Manufacturing: Machine Productivity, Economies of Scale and Technology-Push	Baumers M; Dickens P; Tuck C; Hague R	2016	242	60.50	4
15	Internationalization of Services: A Technological Perspective	Miozzo M; Soete L	2001	236	12.42	24
16	Functions of Innovation Systems as A Framework to Understand Sustainable Technological Change: Empirical Evidence for Earlier Claims	Hekkert Mp; Negro So	2009	225	20.45	14
17	Disruptive Technology Roadmaps	Kostoff RN; Boylan R; Simons GR	2004	215	13.44	21
18	A Review of Selected Recent Advances in Technological Forecasting	Martino JP	2003	212	12.47	23
19	China's manufacturing locus in 2025: With a comparison of "Made-in-China 2025" and "Industry 4.0"	Li L	2018	209	104.50	2
20	Roadmapping A Disruptive Technology: A Case Study the Emerging Microsystems and Top-Down Nanosystems Industry	Walsh ST	2004	207	12.94	22
21	Delphi: A Brief Look Backward and Forward	Linstone HA; Turoff M	2011	206	22.89	12
22	National Learning Systems: A New Approach on Technological Change in Late Industrializing Economies and Evidences from the Cases of Brazil and South Korea	Viotti EB	2002	202	11.22	25
23	Identifying and Evaluating Robust Adaptive Policy Responses to Climate Change for Water Management Agencies in The American West	Lempert RJ; Groves DG	2010	198	19.80	15
24	Sectoral Systems of Environmental Innovation: An Application to the French Automotive Industry	Oltra V; Saint Jean M	2009	197	17.91	18
25	Exploring Sustainability Transitions in the Electricity Sector with Socio-Technical Pathways	Verbong GPJ; Geels FW	2010	196	19.60	17

R=Ranked according to TC=Total citations; C/Y=Citations per year.

(2016) which rank as the top three publications, respectively. These manuscripts are relatively recent but have accumulated citations at a faster pace than other manuscripts in the top 25.

3.1.2. Authors, institutes, and countries

Table 3 ranks the most prolific authors,[2] institutes, and countries contributing to TFSC's SIs based on the total number of publications and citations, respectively. Alan L. Porter, Professor Emeritus of Industrial & Systems Engineering, and Public Policy, currently affiliated with Georgia Institute of Technology (USA), is the most prolific contributor to TFSC's SIs with 16 articles and 664 citations. Ronald N. Kostoff, also

[2] Author affiliations are considered based on the latest paper published in TFSC.

Table 3
Leading authors, institutes, and countries in TFSC-SIs from 1979 to 2019.

AUTHORS							INSTITUTES				COUNTRY			
R	Author	Affiliation	Country	TP	TC	C/P	Institute	TP	TC	C/P	Country	TP	TC	C/P
1	Alan L. Porter	Georgia Institute of Technology	USA	16	664	41.50	Delft University of Technology	29	1015	35.00	United States	295	11,010	37.32
2	Ronald N. Kostoff	Georgia Institute of Technology	USA	13	662	50.92	Utrecht University	28	1701	60.75	United Kingdom	212	8243	38.88
3	Keywan Riahi K	International Institute for Applied Systems Analysis	Austria	9	1310	145.56	International Institute for Applied Systems Analysis, Laxenburg	26	1028	39.54	Netherlands	133	6490	48.80
4	Douglas K.R. Robinson	University of Paris-Est Marne-la-Vallée	France	9	324	36.00	National Research University Higher School of Economics	26	604	23.23	China	133	2783	20.92
5	David Sarong	Brunel University	UK	9	126	14.00	Georgia Institute of Technology	22	617	28.05	Germany	105	3903	37.17
6	Manuel Heitor	Technical University of Lisbon	Portugal	7	145	20.71	The University of Manchester	20	908	45.40	France	94	3545	37.71
7	Jiyong Eom	Sogang University	South Korea	6	535	89.17	Chinese Academy of Sciences	19	453	23.84	Italy	74	2295	31.01
8	David Urbano	The Autonomous University of Barcelona	Spain	6	431	71.83	University of Twente	18	989	54.94	Spain	74	2263	30.58
9	George Wright	Strathclyde University	UK	6	396	66.00	Faculteit Techniek, Bestuur en Management, TU Delft	17	621	36.53	South Korea	72	1832	25.44
10	Heiko A. von der Gracht	Steinbeis University	Germany	6	362	60.33	European Commission Joint Research center	16	174	10.88	Austria	51	3030	59.41
11	Del Giudice M			6	275	45.83	Search Technology Inc	15	434	28.93	Australia	47	1156	24.60
12	Michael B. Briggs	Marine Corps Warfighting Laboratory	USA	6	215	35.83	Instituto Superior Tecnico	14	338	24.14	Taiwan	44	1844	41.91
13	Hugo Horta	The University of Hong Kong	Hong Kong, China	6	77	12.83	Office of Naval Research	13	662	50.92	Japan	40	1479	36.98
14	Yongrok Choi	Inha University	South Korea	6	72	12.00	EBS Universität für Wirtschaft und Recht	13	635	48.85	Russian Federation	35	643	18.37
15	The technology atlas team	Asian and Pacific Center for Transfer of Technology	India	6	54	9.00	Beijing Institute of Technology	13	339	26.08	Finland	34	662	19.47
16	Arnulf Grübler	International Institute for Applied Systems Analysis	Austria	5	919	183.80	Fraunhofer Institute for Systems and Innovation Research ISI	13	264	20.31	Portugal	33	495	15.00
17	Aurélie Méjean	International Research Center on Environment and Development	France	5	430	86.00	University of Strathclyde	13	201	15.46	Sweden	31	902	29.10
18	Elmar Kriegler	Potsdam Institute for Climate Impact Research	Germany	5	399	79.80	University of the West of England	13	160	12.31	Denmark	30	1122	37.40
19	Gunnar Luderer	Potsdam Institute for Climate Impact Research	Germany	5	379	75.80	Friedrich-Alexander-Universität Erlangen-Nürnberg	12	540	45.00	Canada	29	1310	45.17
20	Ling Li	Old Dominion University	USA	5	276	55.20	Tsinghua University	12	261	21.75	Switzerland	21	810	38.57
21	Harold A. Linstone	Portland State University	USA	5	262	52.40	Copernicus Institute of Sustainable Development	12	197	16.42	Brazil	20	844	42.20
22	Ying Guo	Beijing Institute of Technology	China	5	198	39.60	University of Chinese Academy of Sciences	12	195	16.25	India	20	739	36.95
23	Christofer Laurell	Stockholm School of Economics Institute for Research	Sweden	5	108	21.60	PBL Netherlands Environmental Assessment Agency	11	501	45.55	Belgium	18	498	27.67
24	Dirk Meissner	National Research University Higher School of Economics	Russia	5	87	17.40	The University of New Mexico	11	451	41.00	Iran	17	242	14.24
25	Jerome C. Glenn	American Council for the United Nations University	USA	5	40	8.00	University of Kent	11	257	23.36	Singapore	13	337	25.92

Notes: *R*=Rank according to TP=Total papers; TC=Total citations; C/P=Citation per paper

currently affiliated with the Georgia Institute of Technology (USA), ranked second with 13 papers and 662 citations. In the third place is Keywan Riahi from the International Institute for Applied Systems Analysis (IIASA, Austria) with nine articles and 1310 citations i.e. the highest citation among the top 25 contributing authors of TFSC's SIs.

Among the top 25 centers of excellence that regularly publish in TFSC's SIs, Delft University of Technology (Netherlands), ranked first with 29 articles (TC:1015; C/P:35). Utrecht University, Netherlands, is the second most productive institute with 28 publications (TC: 1701; C/P: 60.75) and the International Institute for Applied Systems Analysis, Austria, is on the third with 26 publications (TC: 1028), (C/P: 39.54). It is curious that the Georgia Institute of Technology, which has the two most productive TFSC's SIs authors (Alan Porter and Ronald Kostoff), remains in the fifth place. This anomaly stems from the fact that the two authors had published several manuscripts with other affiliations as well. It indicates that the Georgia Institute of Technology remains a center of excellence with a strong cluster of prolific TFSC's SI researchers and improving institutional profile.

As for the countries, United States tops the ranking with 295 research papers (TC: 11,010 citations), while United Kingdom ranked second with 212 articles (TC: 8243). They are followed by the Netherlands (TC: 6490) and China (TC: 2783) at the third position with 133 papers.

3.2. Top ten authors, universities, and countries citing TFSC's SIs

It is equally important for journals to identify actors who are actively citing studies that appear in the journal. Table 4 highlights the top ten authors, institutes, and countries that most often cite manuscripts that appear in TFSC's SIs. Keywan Riahi from the International Institute for Applied Systems Analysis (IIASA, Austria) ranked first with a total of 96 cited papers. Tugrul Daim from the Portland State University (TC: 79) and Alan Porter, affiliated with Georgia Institute of Technology (TCP: 76), are the second and third ranked citing authors of TFSC's SI manuscripts, respectively. Similarly, the top manuscript producing institutes also remain the top three citing institutes and countries for TFSC's SIs. The top three universities are Delft University of Technology (TCP: 414), Utrecht University (TCP: 401), and International Institute for Applied Systems Analysis (TCP: 329), while the top 3 countries are USA (TCP: 4420), UK (TCP: 3889), and China (TCP: 3742).

Table 4
Top authors, affiliated universities and countries citing TFSC-SIs from 1979 to 2019.

R	Authors	TCP	Universities	TCP	Countries	TCP
1	Keywan Riahi	96	Delft University of Technology	414	USA	4420
2	Tugrul U. Daim	79	Utrecht University	401	UK	3889
3	Alan L. Porter	76	International Institute for Applied Systems Analysis	329	China	3742
4	Robert Phaal	59	Wageningen University & Research	314	Germany	2147
5	Detlef P. van Vuuren	59	The University of Manchester	278	Netherlands	2107
6	Volker Krey	56	Chinese Academy of Sciences	270	Italy	1725
7	Tan Yigitcanlar	51	University of Cambridge	245	Spain	1555
8	Gunnar Luderer	48	Copernicus Institute of Sustainable Development	240	Australia	1519
9	Sangho Lee	47	Portland State University	238	France	1165
10	Yongtae Park	44	Tsinghua University	222	India	1111

Note: *R*=Ranked by TCP=Total cited papers

3.3. Top ten journals citing TFSC's SIs and cited by TFSC

Table 5 identifies the top ten journals that are most often cited in TFSC's SIs and those that cite TFSC's SI manuscripts. The former demonstrates the list of journals that impact the development of knowledge in TFSC's SIs (knowledge inflow), while the latter indicates the journals that are influenced by the knowledge created by TFSC's SIs (knowledge outflow). This list indicates that knowledge inflow to TFSC's SIs stems from quality journals as 90% are rated as "3″ or above by Academic Journal Guide (AJG) and 100% are rated as "A" or above by the Australian Business Deans Council (ABDC). The top three journals are Academy of Management Review (TCP: 556), Academy of Management Journal (TCP: 458), and Administrative Science Quarterly (TCP: 424), respectively. Similarly, the quality of TFSC's SIs knowledge outflow also remain high as 80% of journals in the top ten are rated as "2″ or above by AJG and 90% are rated as "B" and above by ABDC. The top three journals that cite TFSC's SIs most frequently are TFSC itself (TCP: 1903), Sustainability Switzerland (TCP: 966), and Journal of Cleaner Production (TCP: 707).

3.4. Knowledge clusters

Bibliographic coupling remains a common method to cluster documents based on the similarities in their bibliographies (Khan et al., 2021; Li et al., 2017; Mas-Tur et al., 2021). Using bibliographic coupling, seven research clusters with a minimum of 100 documents each were extracted using 1171 (89.4%) of TFSC's SI manuscripts (see Table 6). Fig. 2 provides an evolutionary profile of these clusters over the years. The following section provides an overview of these clusters and identifies the dominant themes based on keyword co-occurrences along with the top manuscripts, authors, and institutes (centers of excellence) that have been instrumental in the development of these clusters (see Table 7).

The first cluster (Planning for the Future) consists of 240 coupled papers which represents 18.33% (240 of 1309) of TFSC's SI documents. However, it has accumulated a disproportionally higher number of citations, 25.43% of the total (TC: 10,368 of 40,768). In addition, this cluster has the highest h-index (56) and g-index (90) among all the clusters. Common keyword themes in chronological order of importance are text mining, Delphi, foresight, scenario planning, and road mapping (see Fig. 3a). The most influential article in this cluster is by Phaal et al. (2004) titled "*Technology roadmapping—a planning framework for evolution and revolution*" with 650 citations wherein they discuss the road mapping techniques and the different perspectives that it offers. Daim et al. (2006) study on "F*orecasting emerging technologies: use of bibliometrics and patent analysis*" with 599 citations remain the second most cited article in this cluster. They highlight the limitations of forecasting emerging technologies as they generally lack historical data. They, therefore, propose the use of bibliometrics and patent analysis for forecasting and demonstrate its application for three emerging technologies of fuel cells, food safety, and optical storage. Hasson and Keeney (2011) study on "*Enhancing rigor in the Delphi technique research*" ranked third with 265 citations. Their methodology-centric manuscript focuses on the Delphi technique and issues of establishing rigor for it based on the trinity of reliability, validity, and trustworthiness. The top authors of this cluster are Porter AL (TP: 15), Kostoff RN (TP: 12), and Von Der Gracht HA (TP: 8). As for the centers of excellences, Search Technology leads the ranking (TP: 13), followed by Office of Naval Research (TP: 12), and Delft University of Technology (TP:10).

The second cluster (Climate Change & Energy) covers 13.59% (178 of 1309) of the TFSC's SI documents and with 14.49% (TC: 5908 of

Table 5
Top journals citing TFSC-SIs and cited in TFSC-SIs between 1979 and 2019.

R	Journal cited in TFSC (Knowledge Inflows)	ABS	ABDC	TCP	Journal citing TFSC (Knowledge Outflows)	ABS	ABDC	TCP
1	Academy of Management Review	4*	A*	556	Technological Forecasting and Social Change	3	A	1903
2	Academy of Management Journal	4*	A*	458	Sustainability Switzerland	NR	NR	966
3	Administrative Science Quarterly	4*	A*	424	Journal of Cleaner Production	2	A	707
4	American Economic Review	4*	A*	235	Energy Policy	2	A	290
5	California Management Review	3	A	157	Futures	2	B	229
6	Computers in Human Behavior	3	A	155	Technology Analysis and Strategic Management	2	B	205
7	Ecological Economics	3	A	144	Research Policy	4*	A*	201
8	Energy Economics	3	A*	165	Journal of Business Research	3	A	187
9	Energy Policy	2	A	377	Scientometrics	2	A	183
10	European Journal of Operational Research	4	A*	212	Environmental Innovation and Societal Transitions	NR	B	154

Table 6
TFSC-SIs Clusters.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7
Panel A. Descriptive statistics							
Total publications (TP)	240	178	177	166	154	137	119
Total Citations (TC)	10,368	5908	6438	3578	3718	6153	3763
Average citations (C/P)	43.2	33.19	36.37	21.55	24.14	44.91	31.62
Average citations per year per doc (C/Y/P)	4.307	5.635	4.53	4.181	3.711	4.552	6.327
h-index	56	38	41	29	35	42	35
g-index	90	68	73	49	51	74	56
Panel B. Document type							
article	239	178	175	166	154	134	119
review	1	0	2	0	0	3	0
Author's Keywords	821	736	644	690	576	494	529
Panel C. Co-authorship information							
Number of contributing authors (NCA)	711	673	416	449	407	362	390
Authors of single-authored documents (ASA)	34	27	38	28	22	36	4
Authors of co-authored documents (ACA)	514	485	348	354	348	299	355
Single-authored documents (SA)	36	27	41	29	23	36	4
Co-authored documents (CA)	204	151	136	137	131	101	115
Collaboration index (CI)	2.52	3.21	2.56	2.58	2.66	2.96	3.09

Note: This table compares the descriptive indicators of all clusters of TFSC-SIs published between 1979 and 2019.

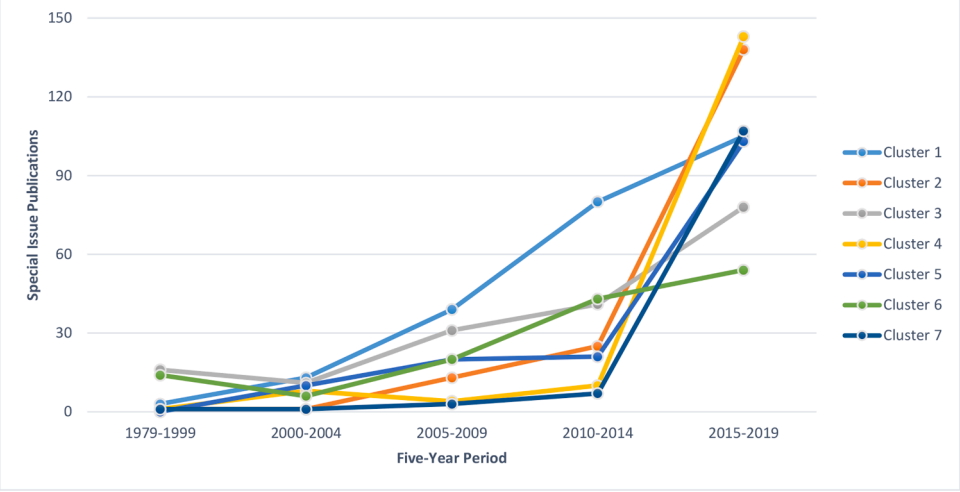

Fig. 2. Cluster Evolution from 1979 - 2019.

40,768) citations. This cluster carries the highest collaboration index (CI: 3.21), indicating that on average papers written in this cluster are a result of collaboration between slightly bigger teams than other clusters. Dominant themes in this cluster in chronological order of importance are climate change, climate policy, sustainability, crowd-funding, and big data (see Fig. 3b). Riahi et al. (2007) study on "*Scenarios of long-term socioeconomic and environmental development under climate stabilization*" is the most influential article with 674 citations. This study also ranked as the top-cited article among all TFSC's SI articles published between 1979 and 2019. The authors demonstrated in their study that the energy sector remains the largest source of GHG emissions and, therefore, is the prime target of emissions reduction. The study by Fischer et al. (2007) titled "*Climate change impacts on irrigation water requirements: effects of mitigation, 1990–2080*" ranked second with 345 citations. Using simulations from 1990 to 2080 for irrigated land, irrigation water usage, and withdrawals along with the impact of climate change, they demonstrated that mitigating climate change has significant positive effects compared with unmitigated climate change. Another article by Riahi

Table 7
Cluster wise top papers, authors and institutes (Centers of Excellence).

NAME	MAJOR THEMES	PAPERS			AUTHORS			INSTITUTES		
			TC	C/Y		TP	TC		TP	TC
C1: PLANNING FOR THE FUTURE	Text mining, Delphi, Foresight, Scenario Planning, Road mapping	Phaal et al., 2004	650	36.11	Porter AL	15	588	Search Technology	13	424
		Daim et al., 2006	599	37.44	Kostoff RN	12	639	Office of Naval Research	12	639
		Hasson F; Keeney S, 2011	265	24.09	Von Der Gracht HA	8	372	Delft University of Technology	10	423
		Kostoff et al., 2004	219	12.17	Robinson DKR	7	244	Portland State University	9	1123
		Martino JP, 2003	215	11.32	Wright G	6	411	EBS Business School	9	560
		Linstone Ha; Turoff M, 2011	211	19.18	Briggs MB	5	188	School of Management and Economics, Beijing Institute of Technology, Beijing, China	9	228
		Lempert Rj; Groves Dg, 2010	199	16.58	Darkow IL	4	255	University of Strathclyde	7	112
		Phaal R; Muller G, 2009	174	13.39	Guo Y	4	192	University of Cambridge	6	1000
		Rowe G; Wright G, 2011	168	15.27	Durance P	4	161	Georgia Institute of Technology	6	308
		Rohrbeck R; Gemnden Hg, 2011	160	14.55	Glenn JC	4	41	University of Manchester	6	299
C2: CLIMATE CHANGE & ENERGY	Climate Change, Climate Policy, Sustainability, Crowd funding, Big Data	Riahi et al., 2007	674	44.93	Riahi K	9	1330	International Institute for Applied Systems Analysis	10	2043
		Fischer et al., 2007	345	23	Eom J	5	483	Utrecht University	10	839
		Riahi et al., 2015	182	26	Mjean A	5	423	Jiangxi University of Finance and Economics	8	154
		Wardekker et al., 2010	177	14.75	Kriegler E	5	410	Ben-Gurion University of The Negev	8	102
		De Sousa Jabbour et al., 2018	162	40.5	Luderer G	5	390	University of Chinese Academy of Sciences	7	114
		Tubiello FN; Fischer G, 2007	136	9.07	Van Vuuren DP	5	383	Potsdam Institute for Climate Impact Research	6	598
		El-Kassar AN; Singh SK 2019	132	44	Song M	5	173	Pacific Northwest National Laboratory's Joint Global Change Research Institute	6	532
		Yang et al., 2013	129	14.33	Bosetti V	4	409	Pbl Netherlands Environmental Assessment Agency	6	512
		Grbler et al., 2007	125	8.33	Capros P	4	340	Inha University	6	82
		Kriegler et al., 2015-a	111	15.86	Choi Y	4	50	Jinan University	6	62
C3: INNOVATIVE TECHNOLOGIES	Innovation, China, Diffusion, 3D Printing, Sharing Economy	Rayna T; Striukova L, 2016	284	47.33	Walsh ST	4	295	University of Manchester	8	444
		Baumers et al., 2016	251	41.83	Dismukes JP	4	81	University of New Mexico	6	335
		Miozzo M; Soete L, 2001	237	11.29	Harms R	3	123	University of Twente	5	165
		Muller et al., 2018	211	52.75	Linton JD	3	78	Lancaster University	5	15
		Steven T. Walsh, 2004	209	11.61	Gibson DV	3	51	Delft University of Technology	4	66
		Eduardo B. Viotti, 2002	203	10.15	Sung TK	3	28	Kyonggi University	4	52
		Oltra V; Jean MS, 2009	198	15.23	Birchenhall C	2	76	Seoul National University	4	14
		Acquier et al., 2017	171	34.2	Ciarli T	2	76	Manchester Metropolitan University Business School	3	76
		Cowan R; Hultén S, 1996	170	6.54	Bers JA	2	54	George Mason University	3	25
		Bogers et al., 2016	162	27	Blind K	2	53	Leeds University Business School	3	20
C4: ENTREPRENEURSHIP AND INNOVATION	Innovation, Absorptive capacity, Iran, Open innovation, Entrepreneurship	Ling Li, 2018	215	53.75	Li L	5	264	Old Dominion University	10	312
		Aparicio et al., 2016	174	29	Sarpong D	5	79	Jilin University	7	40
		Santoro et al., 2018	145	36.25	Chen Y	5	66	Tarbiat Modares University	6	22
		Petrick IJ; Echols AE, 2004	144	8	Xu X	5	39	University of Kent	5	110

(*continued on next page*)

Table 7 (*continued*)

NAME	MAJOR THEMES	PAPERS			AUTHORS			INSTITUTES		
			TC	**C/Y**		**TP**	**TC**		**TP**	**TC**
		Bresciani et al., 2018	118	29.5	Zhao S	5	19	University of Groningen	5	95
		Turr et al., 2014	79	9.88	Urbano D	4	349	Coventry University	5	91
		Urbano D; Aparicio S, 2016	76	12.67	Dong JQ	4	77	University of The West of England	5	79
		Oliveira et al., 2002	66	3.3	Zhang W	4	37	American University of Sharjah	5	39
		Ben Arfi et al., 2018	63	15.75	Aparicio S	3	270	Sharif University of Technology	5	26
		Sousa I; Wallace D, 2006	63	3.94	Amankwah-Amoah J	3	70	Beijing Normal University	4	38
C5: INNOVATION ECO-SYSTEM	Patents, Innovation, Technology Transfer, Triple Helix, Entrepreneurial University	Landry et al., 2002	312	15.6	Heitor M	10	135	Tsinghua University	7	97
		Curran CS; Leker J 2011	158	14.36	Horta H	6	80	University of Lisbon	5	124
		Mazzucato M; Semieniuk G, 2018	110	27.5	Guerrero M	2	96	University of Campinas	5	20
		Gao et al., 2013	90	10	Edler J	2	79	The University of Hong Kong	4	80
		Tseng et al., 2011	86	7.82	Conceiao P	2	61	National Research University Higher School of Economics	4	65
		Rutten R; Boekema F, 2007	86	5.73	Etzkowitz H	2	54	Seoul National University	4	61
		Islam N; Miyazaki K, 2009	76	5.85	Li X	2	28	Kyung Hee University	4	36
		Georg Reischauer, 2018	72	18	Carayannis EG	2	25	Instituto Superior Tcnico	3	176
		Kuhlmann S; Edler J, 2003	61	3.21	Chen SH	2	25	Instituto Universitrio De Lisboa (Iscte-Iul)	3	50
		Tsai et al., 2009	60	4.62	Fischer BB	2	20	National Chiao Tung University	3	23
C6: SUSTAINABILITY	Back casting, Innovation, Multi-level perspective, Technology assessment, Sustainability	Schot J; Rip A, 1997	454	18.16	Wieczorek AJ	3	193	Delft University of Technology	11	338
		Frank W. Geels, 2005	403	23.71	Van Lente H	3	87	Utrecht University	9	683
		Lee et al., 2014	333	41.63	Suopajrvi T	3	72	University of Twente	7	618
		Hekkert MP; Negro SO, 2009	227	17.46	Geels FW	2	602	Erasmus University Rotterdam	6	217
		Verbong GPJ; Geels FW, 2010	199	16.58	Alkemade F	2	125	Eindhoven University of Technology	4	343
		Foxon et al., 2010	186	15.5	Angel D	2	88	University of Oulu	4	72
		Van De Kerkhof M; Wieczorek A, 2005	154	9.06	Eames M	2	74	Cardiff University	3	284
		Kok et al., 2011	149	13.55	Avelino F	2	73	Clark University	3	158
		Robinson et al., 2011	149	13.55	Giurco D	2	59	Kyoto University	3	61
		Ruud E.H.M. Smits, 2002	140	7	Faulkner A	2	29	Institute of Technology Assessment	3	2
C7: SOCIAL MEDIA & INTERNET OF THINGS	Social Media, Internet of Things, Smart Tourism, Acculturation, Big Data Analytics	Wang et al., 2018	363	90.75	Chen SC	3	149	Yuan Ze University	5	44
		Hsu YH; Fang W, 2009	255	19.62	Laurell C	3	99	Newcastle University Business School	4	100
		Schwarz N; Ernst A, 2009	170	13.08	Sandstrm C	3	99	The University of Western Australia	4	72
		Scott G. Dacko, 2017	113	22.6	Chung N	2	96	Florida Atlantic University	4	69
		Huang Z; Benyoucef M, 2015	91	13	Chang V	2	77	University of Kent	4	49
		Rese et al., 2017	83	16.6	Barlatier PJ	2	42	Kyung Hee University	3	96
		Chung et al., 2015	77	11	Cegarra-Navarro JG	2	28	Ton Duc Thang University	3	45
		Chen SC; lin CP, 2015	67	9.57	Akhtar P	2	25	Rmit University	3	42
		Blazquez D; Domenech J, 2018	66	16.5	Dora M	2	23	Feng Chia University	3	40
		Chang et al., 2015	65	9.29	Chen Y	1	3	Coventry University	3	31

Note: *R*=Rank according to TP=Total papers; TC=Total citations; C/Y=Citation per year.

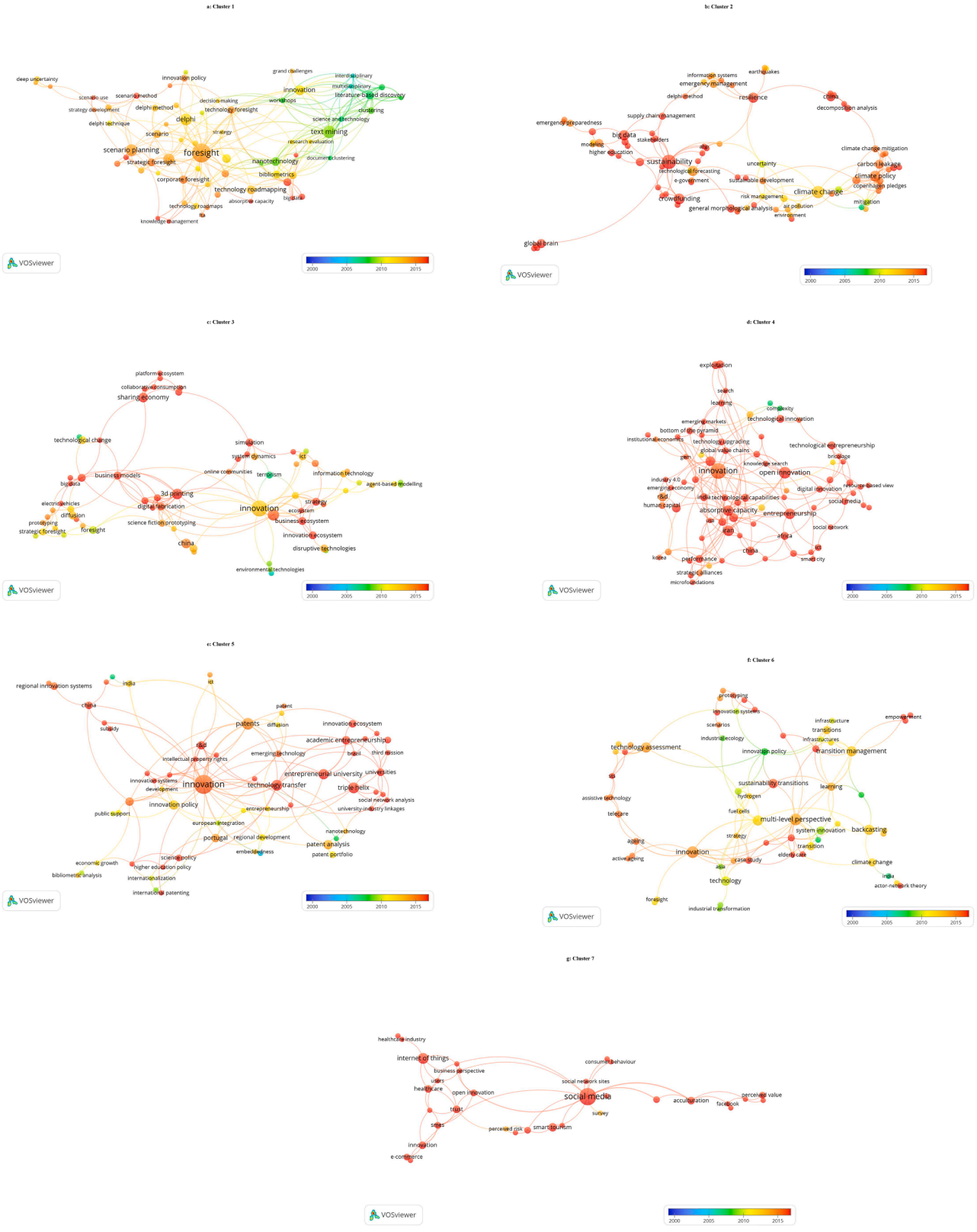

Fig. 3. Key themes based on keyword co-occurrences.

et al. (2015) titled "*Locked into Copenhagen pledges — Implications of short-term emission targets for the cost and feasibility of long-term climate goals*" with 182 citations ranked third. They argued against the policy proposals of Copenhagen Accord and Cancun Agreement, as they demonstrated, using AMPERE modeling, that following such proposals would lead to more "lock-in" situation of energy system in fossil fuels, higher mitigation costs, and missed long-term climate objectives. The highest number of paper publishing authors in this cluster are Riahi K (TP: 9), Eom J (TP: 5), and Mjean A. (TP: 5). The top three centers of excellence are the International Institute for Applied Systems Analysis (TP: 10), Utrecht University (TP: 10), and Jiangxi University of Finance and Economics (TP: 8).

The third cluster (Innovative Technologies) represents 13.52% (TP: 177 of 1309) articles and 15.79% (TC: 6438 of 40,768) citations. In terms of citations, it remains the second most impactful cluster. Major Key themes in chronological order of importance are innovation; China, diffusion, 3D printing, and sharing economy (see Fig. 3c). The most influential work in this study was by Rayna and Striukova (2016) titled "*From rapid prototyping to home fabrication: how 3D printing is changing business model innovation*" with 284 citations. This paper discusses the impact of 3D printing on business models and its innovation across its four phases of rapid prototyping and tooling, digital manufacturing, and home fabrication. The second most cited paper was by Baumers et al. (2016) titled "*The cost of additive manufacturing: machine productivity, economies of scale and technology-push*" with 251 citations. They constructed a model for two different types of Additive Manufacturing (AM), electron beam melting and direct metal laser sintering, to compare cost performance and demonstrate that despite the absence of amortizable tooling costs, the economies of scale are still achievable in AM. The third most influential paper in this cluster was by Miozzo and Soete (2001) titled"*Internationalization of services: a technological perspective*" with 237 citations. They examined the technology-intensive service sectors and proposed policy implications for the less-developed nations. Leading authors in this cluster were Walsh ST (TP: 4), Dismukes JP (TP: 4), and Harms R (TP: 3). Moreover, University of Manchester (TP: 8) is the leading center of excellence in this cluster, followed by University of New Mexico (TP: 6), and University of Twente (TP: 5).

Cluster four (Entrepreneurship and Innovation) consists of 12.68% (TP: 166 of 1309) of publications and 8.77% (TC: 3578 of 40,768) citations. Dominant themes of this cluster in chronological order of importance are innovation, absorptive capacity, Iran, open innovation, and entrepreneurship (see Fig. 3d). Li (2018) study on "*China's manufacturing locus in 2025: with a comparison of 'Made-in-China 2025' and 'Industry 4.0'*" remains the most impactful work of this cluster with 215 citations. In this study, the author compares China's "Made-in--China 2025″ plan with Germany's "Industry 4.0″ plan to demonstrate an upward trajectory in China's manufacturing capability, research and development commitment, and human capital investment. Aparicio et al. (2016) article titled "*Institutional factors, opportunity entrepreneurship and economic growth: panel data evidence*" with 174 citations is the second most influential study. Using an unbalanced panel data of 43 countries (2004–2012), they found that informal institutions have a higher impact on opportunity entrepreneurship than formal institutions. Santoro et al. (2018) study titled "*The Internet of Things: building a knowledge management system for open innovation and knowledge management capacity*" ranked third with 145 citations. Using structural equation modeling on data of 298 Italian firms, they demonstrated that as IoT offers new business opportunities, knowledge management systems can help create an open and collaborative ecosystem. Li L, Sarpong D, and Chen Y are the top three leading authors with five publications each. Old Dominion University (TP: 10) tops the list of centers of excellences followed by Jilin University (TP: 7) and Tarbiat Modares University (TP: 6).

Cluster five (Innovation Eco-System) represents 11.76% (TP: 154 of 1309) of articles and 9.11% (TC: 3718 of 40,768) of citations. Major themes in this area in order of chronological importance are patents, innovation, technology transfer, triple helix, and entrepreneurial university (see Fig. 3e). Landry et al. (2016) study titled "*Strategy deployment in healthcare services: a case study approach*" ranks as the most impactful in this cluster with 312 citations. They analyze the logistics deployment strategy of two Canadian hospitals and identify that for a successful deployment, it is imperative that the organization must have (i) a clearly defined strategic intent and (ii) the ability to conduct a series of experimental logistic practices. Curran and Leker (2011) study "*Patent indicators for monitoring convergence – examples from NFF and ICT*" is another influential study of this cluster with 158 citations. Using patent references and International Patent Classification (IPC) co-classification trends, they argue that over time industries have malleable boundaries and different types of companies converge to create new opportunities and threats, e.g., both food and pharmaceutical industries converge to compete in Nutraceuticals and Functional Foods (NFF). The third most influential study was by Mazzucato and Semieniuk (2018) titled "*Financing renewable energy: who is financing what and why it matters*" with 110 citations wherein they analyze the risk and reward mechanism for investments in renewable energy. They find that high-risk technologies are increasingly dependent on investments from a small subset of actors for financing. As for the leading authors and centers of excellence, Heitor M (TP: 10), Horta H (TP: 6,) and Guerrero M (TP: 2) lead the authors ranking, while Tsinghua University, (TP: 7) University of Lisbon (TP: 5) and University of Campinas (TP: 5) lead the ranking for centers of excellences.

The sixth cluster (Sustainability) consists of 10.46% (TP: 137 of 1309) publications and 15.09% of total citations (TC: 6153 of 40,768). Interestingly, this cluster ranked first based on average citations per paper (C/P: 44.91), which indicates that on average papers published in this cluster are more impactful than those in other clusters. Key themes in this cluster based chronological order of importance are backcasting, innovation, multilevel perspective, technology assessment, and sustainability transitions (see Fig. 3f). The most impactful study in this cluster was by Schot and Rip (1997) titled "*The past and future of constructive technology assessment*" with 454 citations. It discussed the family of technology assessment approaches (Constructive Technology Assessment-CTA) developed in the Netherlands and Denmark. Geels (2005) study "*Processes and patterns in transitions and system innovations: refining the co-evolutionary multi-level perspective*" which investigate transitions at the level of societal functions (transport, communication, and housing) ranked second with 403 citations. Their work is followed in terms of impact by Lee et al. (2014) study "*Towards an effective framework for building smart cities: lessons from Seoul and San Francisco*" with 333 citations. This study explores the process of building an effective smart city by using comparative case studies and proposes a conceptual framework with eight different facets of it. The three leading authors in this cluster are Wieczorek AJ, Van Lente H, and Suopajrvi T with all having three papers each to their credit. While the Delft University of Technology with (TP: 11) ranks first, Utrecht University (TP: 9) second, and University of Twente (TP: 7) as third among the centers of excellence for this cluster.

The last cluster (Social Media & Internet of Things) is the smallest of all clusters with only 9.09% (TP: 119 of 1309) of publications and 9.23% (TC: 3763 of 40,768) citations. Albeit the smallest, this cluster has the highest average Citations per Year per Paper (C/Y/P: 6.327) which indicates that on an annual basis papers published in this cluster are more impactful than other clusters, indicating the promising future of the studies published in this cluster. Major themes covered in this cluster are social media, internet of things, smart tourism, acculturation, and big data analytics (see Fig. 3g). Interestingly, all these themes remain chronologically similar alluding to the nascent and emerging nature of this cluster. Wang et al. (2018) paper on "*Big data analytics: understanding its capabilities and potential benefits for healthcare organizations*" with 363 citations ranked as the most impactful study of this cluster. Using content analysis of 26 big data implementation cases in the health industry, the authors identified five recommended strategies for success.

Hsu and Fang (2009) study titled "*Intellectual capital and new product development performance: the mediating role of organizational learning capability*" follows in impact with 255 citations. They discussed the relationship between intellectual capital, organizational learning capability, and new product development performance. The third most impactful study in this cluster is by Schwarz and Ernst (2009) titled "*Agent-based modeling of the diffusion of environmental innovations — an empirical approach*" with 170 citations. They predicted that in the nearer future water-saving innovations will diffuse even without promotional efforts. The top three authors in this cluster are Chen SC, Laurell C, and Sandstrm C who all share three publications each. As for centers of excellence, Yuan Ze University ranked first with (TP: 5) while Newcastle University Business School (TP: 4) and the University of Western Australia (TP: 4) ranked second and third.

3.4.1. Review of TFSC themes vs. SI clusters

To identify the differences in the knowledge developed via SI manuscripts, these clusters are compared with the general body of knowledge developed in TFSC. Although, multiple bibliometric reviews of TFSC are published, but Singh et al. (2020) has developed the most exhaustive list of TFSC knowledge's clusters by identifying ten different themes (see Table 8). This study benchmarks their study and compares how SI thematic clusters differ from it. However, it is important to note that thematic clusters identified by Singh et al. (2020) form macro-clusters as it incorporates all the manuscripts of TFSC, including SIs. On the contrary, the clusters identified in this study form a sub-set of the macro clusters as they only focus on SI manuscripts. These micro-SI clusters merit special consideration as they identify knowledge dynamics that are guiding the future research agenda of the journal via special initiatives and are likely to highlight trends not observed in a journal wide macro analysis. A comparative review of the macro TFSC clusters as identified by Singh et al. (2020) and micro-SI cluster of this study reveal two important differences.

Firstly, it is observed that the rank order of similar clusters differs. For example, the cluster that focuses on methodology, ranks 4th in the macro themes but that it ranks 1st among the micro-SI clusters. Similarly, clusters that relate to innovation rank 1st (Technological Innovation),3rd (Innovation Diffusion) and 10th (Innovation System) among the macro clusters but they rank 3rd (Innovative Technologies) and 5th (Innovation Eco-system) among the micro-SIs. Fig. 2 demonstrates that these similar micro-SI clusters (1, 3, and 5) represent historically important domains of interest for the journal , thus a higher correspondence between macro and micro-SI clusters is observed.

Secondly, a more prominent difference stems from the identification of unique micro-SI clusters. These unique micro clusters, due to their emergent nature, are generally smaller and are not visible in a macro analysis where the presence of bigger more established clusters obstruct their identification. This study identifies four unique micro-SI clusters of Climate Change & Energy (Cluster 2), Entrepreneurship and Innovation (Cluster 4), Sustainability (Cluster 6), and Social Media & Internet of Things (Cluster 7). These clusters, in line with their emergent characteristic, have seen a steep rise in the number of publications during the last decade (see Fig 2). Also, as these clusters have a high average citations per year per doc (see Table 6), therefore they will not only shape the future of the TFSC journal but also in how TFSC influences the broader domain of technological forecasting.

Table 8
Thematic Comparison of Regular Issues Vs Special Issues.

Singh et.al. Clusters	**Dominant Themes**	TFSC – SI Clusters **Clusters**	**Dominant Themes**
Technological Innovation	Transition Management; Innovation Studies; Technological change; Innovation Systems	Planning for the Future	Foresight, Text mining, Delphi, Scenario Planning, Road mapping
Competitive advantage	Dynamic Capability; Resource Based View; Complementary Assets; Exploration; Exploitation	Climate Change & Energy	Sustainability, Climate Change, Climate Policy, Crowd funding, Big Data
Innovation Diffusion	Technological Change; Rate of Imitation; Marketing; New Product	Innovative Technologies	Innovation, 3D Printing, China, Diffusion, Sharing Economy
Methodology	Delphi Method; Forecasting Methodology; Scenario Development; Scenario techniques	Entrepreneurship and Innovation	Innovation, Open innovation, Absorptive capacity, Entrepreneurship, Iran, Social entrepreneurship
Technology Acceptance	User Acceptance; End User; Information Technology	Innovation Eco-System	Innovation, Patents, Technology Transfer, Triple Helix, Entrepreneurial University
New Product	Consumer Products; New Product Growth; Innovation; Imitation	Sustainability	Innovation, Multi-level perspective, Back casting, Sustainability, Technology assessment
Technological Transition	Technical Change; Architectural Innovation; Creative Destruction; Absorptive Capacity; Technological Discontinuities	Social Media & Internet of Things	Social Media, Internet of Things, Smart Tourism, Acculturation, Big Data Analytics
Knowledge Creation	Dominant Designs; Exploration; Exploitation; Learning		
Scenario Techniques	Evolution; Overview; Methods Selection		
Innovation System	Sectoral System of Innovation; Innovation System; Technology		

4. Conclusion

Phillips (2014) stated that despite SIs' ability to address "hot" emerging issues, they are not as respected by the academia as RIs. In the absence of any systematic effort to address this dilemma, it remained unclear how TFSC's SIs influenced the field and whether they differ in impact from RIs. This study addresses this issue and provides a state-of-the-art bibliometric review of TFSC's SIs throughout its history (1979–2019) and also benchmarks its performance with RIs to demonstrate their relative contribution to the success of the journal.

Firstly, this study demonstrates that manuscripts published in TFSC's SIs receive significantly higher citations than RIs i.e., 34% more citations, and are also more likely to be cited (SI: 97% vs. RI: 93%). At an aggregate level, TFSC's SIs represent only 30% of the total publication but they represent disproportionally higher 37% contribution to the total citations. In terms of 'hot' papers as represented by 'h' and 'g' index, it is observed that RI performs better than SIs in absolute terms. However, when these metrices are evaluated as percentage of total

manuscripts for each publication type, it is observed that SIs publish nearly twice (5.50%) the number of 'hot papers' than RIs (3.31%) when evaluated with 'h' index; and nearly at the same level (91% of RIs 'g' index) in spite of publishing less than half the number of manuscripts (SI: 1309 vs. RI: 3047). Also, as SIs address current topics of interest, they accumulate citations at a faster rate (20% more) than RIs on a per annum basis.

Secondly, this study undertakes a performance analysis of leading actors (authors, institutes, and countries) that have contributed to the success of TFSC-SIs. The top two leading authors Alan L. Porter (T: 16) and Ronald N. Kostoff (TP: 13) of TFSC's SIs are both currently affiliated with the Georgia Institute of Technology, USA. While the third most productive author Keywan Riahi (TP: 9) is affiliated with International Institute for Applied Systems Analysis, Austria. Overall, the most productive institutes for TFSC's SIs are Delft University of Technology (TP: 29), Utrecht University (TP: 28), and International Institute for Applied Systems Analysis (TP: 26). As for countries, the USA dominates other countries by producing 295 publications and 11,010 citations. Other leading countries are United Kingdom, Netherlands, China, and Germany.

Thirdly, the study identifies the knowledge flow dynamics between TFSC's SIs and other journals. With respect to the intellectual connections with other business and management journals, TFSC's SIs demonstrate strong knowledge inflow connections with the prominent business and society journals such as *Academy of Management Review, Academy of Management Journal, Administrative Science Quarterly* and *American Economic Review*. Whereas the leading journals that cite TFSC's SIs articles, on the other hand, are the *Technological Forecasting and Social Change* (itself), *Sustainability Switzerland, Journal of Cleaner Production,* and *Energy Policy*.

Finally, knowledge clusters of TFSC-SIs are identified along with their prominent actors (authors and institutes) and research themes. The study identified seven major clusters of (i) planning for future, (ii) climate change and energy, (iii) innovative technologies, (iv) entrepreneurship and innovation, (v) innovation ecosystem, (vi) sustainability, and (vii) social media and internet of things. These clusters were then compared against the macro-clusters identified by Singh et al. (2020) for the entire set of manuscripts published in TFSC. Four micro-clusters (Climate Change & Energy, Entrepreneurship and Innovation, Sustainability and Social Media & Internet of Things) that are unique to SIs were highlighted. Evolutionary trends demonstrate that these unique SI clusters are rapidly growing and are likely to define the future trajectory of the journal and its influence on the field.

As the results of bibliometric studies largely depend on the data extracted, therefore the results inherit the limitation of the database. The data for this study was extracted from the Scopus, which remains one of the best sources of bibliometric information.

Authors' statement

Rohail Ashraf Conceptualization; Project administration; Supervision; Validation; Writing - original draft; Writing - review & editing.

Muhammad Asif Khan Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software.

Rafiq Ahmed Khuhro Conceptualization; Writing - original draft; Writing - review & editing.

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Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Appendix A: Annual publications and citations structure of TFSC-SIs between 1979 and 2019

PY	TP	SA	CA	NCA	CNCA	NAY	ACI	TCP	TC	C/P	C/CP	C/P/Y	C/CP/Y	h	g	Publications with citations: 1–49	50–99	>100
1979	8	4	0	16	16	16	1.00	8	85	10.63	10.63	0.26	0.26	5	8	8	0	0
1981	9	6	3	12	28	10	0.33	1	3	0.33	3.00	0.01	0.08	1	1	1	0	0
1982	9	5	4	14	42	12	0.56	9	44	4.89	4.89	0.13	0.13	4	6	9	0	0
1987	6	0	6	20	62	1	2.33	6	54	9.00	9.00	0.27	0.27	4	6	6	0	0
1988	7	5	2	9	71	9	0.29	5	113	16.14	22.60	0.50	0.71	3	7	4	0	1
1989	3	3	0	3	74	0	0.00	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0
1991	13	8	5	20	94	20	0.54	13	209	16.08	16.08	0.55	0.55	7	13	11	1	0
1992	10	8	2	12	106	12	0.20	6	11	1.10	1.83	0.04	0.07	2	2	6	0	0
1993	10	3	7	24	130	24	1.40	9	516	51.60	57.33	1.91	2.12	5	10	8	0	1
1995	15	8	7	24	154	24	0.60	13	109	7.27	8.38	0.29	0.34	6	10	13	0	0
1996	19	14	5	24	178	20	0.26	17	483	25.42	28.41	1.06	1.18	9	19	14	1	2
1997	17	9	8	26	204	22	0.53	16	689	40.53	43.06	1.76	1.87	7	17	13	2	1
1998	7	2	5	14	218	13	1.00	6	199	28.43	33.17	1.29	1.51	5	7	5	0	1
2001	11	4	7	24	242	23	1.18	11	585	53.18	53.18	2.80	2.80	9	11	9	0	2
2002	16	8	8	35	277	32	1.19	16	1034	64.63	64.63	3.59	3.59	10	16	11	1	4
2003	11	5	6	18	295	15	0.64	11	585	53.18	53.18	3.13	3.13	9	11	7	3	1
2004	23	13	10	39	334	34	0.70	22	1813	78.83	82.41	4.93	5.15	16	23	14	3	5
2005	20	7	13	37	371	33	0.85	20	1186	59.30	59.30	3.95	3.95	15	20	13	5	2
2006	18	5	13	43	414	38	1.39	18	1110	61.67	61.67	4.40	4.40	14	18	13	4	1
2007	34	3	31	114	528	85	2.35	34	2161	63.56	63.56	4.89	4.89	20	34	24	6	4
2008	13	3	10	38	566	14	1.92	13	500	38.46	38.46	3.21	3.21	12	13	10	3	0
2009	49	7	42	135	701	119	1.76	49	2782	56.78	56.78	5.16	5.16	29	49	32	9	8
2010	52	18	34	122	823	110	1.35	52	2675	51.44	51.44	5.14	5.14	28	51	31	12	8
2011	53	4	49	145	968	125	1.74	53	3211	60.58	60.58	6.73	6.73	34	53	30	13	10
2012	22	7	15	46	1014	33	1.09	22	733	33.32	33.32	4.16	4.16	13	22	16	5	1
2013	52	8	44	145	1159	121	1.79	52	2116	40.69	40.69	5.81	5.81	28	45	33	16	3
2014	61	4	57	179	1338	157	1.93	60	1885	30.90	31.42	5.15	5.24	22	42	50	7	3
2015	122	26	96	458	1796	318	2.75	121	3124	25.61	25.82	5.12	5.16	34	48	105	13	2
2016	111	18	93	306	2102	239	1.76	109	2706	24.38	24.83	6.09	6.21	27	46	98	7	4
2017	143	17	126	408	2510	314	1.85	142	3300	23.08	23.24	7.69	7.75	31	47	125	10	5
2018	152	19	133	482	2992	363	2.17	151	4019	26.44	26.62	13.22	13.31	31	54	135	7	8

(*continued on next page*)

(*continued*)

PY	TP	SA	CA	NCA	CNCA	NAY	ACI	TCP	TC	C/P	C/CP	C/P/Y	C/CP/Y	h	g	Publications with citations: 1–49	50–99	>100
2019	213	23	190	674	3666	465	2.16	202	2728	12.81	13.50	12.81	13.50	27	39	191	9	1
Total	**1309**	**274**	**1035**	**3666**				**1267**	**40,768**							**1045**	**137**	**78**

Notes: PY=Publication year; TP=Total papers; SA=Single-author documents; CA=Co-authors documents; NCA=Number of contributing authors; CNCA=Cumulative NCA; NAY=New authors per year; ACI=Annual collaboration index; TCP=Total cited papers; TC=Total citations; C/P=Citations per paper; C/CP=Citations per cited paper; C/P/Y= Citations per paper per year; C/CP/Y= Citations per cited paper per year; h-index; g-index

Appendix B: Definitions of descriptive variables

Variable	Definition
Publication	
Total publications (TP)	The variable shows the academic contributions of the contributing author(s), and/or their affiliation(s). It is measured as the total number of publications in any given year of *TFSC*, the number of publications accredited to a *TFSC* author or an author's affiliation.
Number of cited publication (NCP)	This variable measures the number of *TFSC* research found impactful i.e. cited at least once in Web of Science.
Total citations (TC)	As an indicator of the aura of academic influence, the variable is defined as the sum of total citations accredited to *TFSC* articles, its authors, and (or) their affiliations.
Citations per publication (C/P)	The variable indicates the average citations to *TFSC* articles, measured as the ratio between total citations and total publications.
Citations per cited publication (C/CP)	The variable is an indicator of the average number of citations to the cited articles in *TFSC*.
h-index	As a popular indicator of academic influence, the variables shows the 'h' number of articles cited at least 'h' number of times.
g-index	Indicating academic impact, the variable shows the 'g' number of highly cited articles receiving at least 'g^{2}' citations.
Number of active years (NAY)	Indicating publishing activity, the variable shows the number of years *TFSC*, its author, and (or) their affiliations are found active by publishing at least one article in any given year.
Number of contributing authors (NCA)	As an indicator of academic quality, this variable is measured as the total number of author(s) contributing to the *TFSC* article(s).
Number of affiliated authors (NAA)	Excluding author(s)' repetitions, this variable highlights the head counts of authors who have published in *TFSC*.
Cumulative number of affiliated authors (CNAA)	It is the cumulative count of NAA.
Authors of single-authored articles (ASA)	The variable measures the total number of authors who have contributed single-authored documents to *TFSC*.
Authors of co-authored articles (ACA)	The variable measures the total number of authors who have contributed multi-authored documents to *TFSC*.
Single-authored articles (SA)	The variable shows the number of sole-authored *TFSC* articles.
Co-authored articles (CA)	The variable highlights the number of multi-authored *TFSC* articles.
Collaboration index (CI)	The index shows the number of authors a lead *TFSC* author associates/collaborates to contribute a work of research. It is measured as: $\frac{NCA}{TP} - 1$.
Annual collaboration index (ACI)	The variable shows the annual collaboration index in *TFSC*.
Number of author affiliating countries (NAAC)	As an indicator of the global spread of *TFSC*, the variable shows the total number of countries to which *TFSC* authors have affiliations.

Note: This table presents the definition of the descriptive variables of the study.

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