EXPLORING THE DISCONNECT BETWEEN THE BODIES OF LITERATURE PERTAINING TO SOCIO-TECHNICAL TRANSITIONS AND TECHNOLOGY MANAGEMENT (PART 1): A BIBLIOMETRIC ANALYSIS

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ABSTRACT

The purpose of the bibliometric analysis documented in this article is to investigate the degree of overlap or disconnect between the bodies of literature pertaining to technology management and socio-technical transitions. There is a general agreement in the literature that technology has an indispensable role to play in realising the promise of sustainable societies; this paper considers a specific relationship within this technology-social context — namely, the link between technology management and socio-technical transitions. The importance and value of integrating the concepts of technology management and socio-technical transitions have been highlighted in the literature. However, the extent to which these concepts have been considered together and/or the extent to which they are disconnected has not been elucidated. This study thus considers the respective scientific networks, compares them from a number of bibliometric perspectives, and concludes that no concrete evidence of integration or significant similarity in foundational concepts used in both bodies of literature is evident; and so the study further highlights the need for more research efforts that focus on both bodies of knowledge to support and enable efforts to integrate the concepts of technology management and socio-technical transitions.

OPSOMMING

Die doel van die bibliometriese analise wat in hierdie artikel gedokumenteer word, is om die mate van oorvleueling of ontkoppeling tussen die liggame van literatuur met betrekking tot tegnologiebestuur en sosio-tegniese oorgange te ondersoek. Daar is 'n algemene ooreenkoms in die literatuur dat tegnologie 'n onontbeerlike rol het om te speel in die verwesenliking van die belofte van volhoubare samelewings; hierdie referaat oorweeg 'n spesifieke verhouding binne hierdie tegnologie-sosiale konteks - naamlik die skakel tussen tegnologiebestuur en sosio-tegniese oorgange. Die belangrikheid en waarde van die integrasie van die konsepte van tegnologiebestuur en sosio-tegniese oorgange is in die literatuur uitgelig. Die mate waarin hierdie begrippe saam oorweeg is en/of die mate waarin hulle ontkoppel is, is egter nie toegelig nie. Hierdie studie oorweeg dus die onderskeie wetenskaplike netwerke, vergelyk hulle vanuit 'n aantal bibliometriese perspektiewe, en kom tot die gevolgtrekking dat geen konkrete bewyse van integrasie of betekenisvolle ooreenkoms in grondbeginsels wat in beide literatuurliggame gebruik word, duidelik is nie; en so beklemtoon die studie verder die behoefte aan meer navorsingspogings wat op beide kennisliggame fokus om pogings te ondersteun en moontlik te maak om die konsepte van tegnologiebestuur en sosio-tegniese oorgange te integreer.

1 INTRODUCTION

There is an increasing consciousness and understanding that addressing resource scarcity, and the numerous sustainability challenges that we face on a global scale — specifically, those related to fossil energy use

and climate change — represent a grand challenge. The deep structural changes that are required to achieve the environmental and developmental improvements that will adequately address these challenges are referred to as 'sustainability transitions' or 'socio-technical transitions' towards sustainability [1]-[3]. A socio-technical transition can be described as a set of processes that lead to a fundamental transformation of, or shift in, socio-technical systems [4]. Transitions are multi-actor, multi-factor systems that typically unfold over a considerable number of years [5], and that are seen as co-evolutionary processes between technological and societal factors [6].

A number of approaches to sustainability are proposed in the literature, ranging from radical policy transformations to fundamental changes in the socio-cultural dimensions. However, throughout the literature there is a general consensus that aiming to address sustainability challenges without technology would be difficult, with the leading authors being Jeffrey Sachs[1] and Gunter Pauli[2]. Technological innovation is regarded as an indispensable element in the quest to solve global challenges such as sustainability, and the mounting public concern and demands for intergenerational justice for future societies are putting pressure on policy-makers to support technological innovations in order to realise environmental, economic, and social sustainability [7]. It is evident that the development, diffusion, and management of technology that contributes to addressing sustainability is regarded as one of the key pathways towards sustainable futures [8]. Ittipanuvat, Fujita, Sakata and Kajikawa [7] argue that broader analytical perspectives and a clear understanding of the linkages between technology and social issues are fundamental when aiming to address and respond to complex global challenges such as sustainability, and so they highlight the interrelationship between technology and socio-technical transitions.

Geels [9] (p.1257) states that "*technology, of itself, has no power, does nothing*". This statement highlights the fact that only in conjunction with society, institutions, governing bodies, and organisations can technological innovation fulfil its function and contribute to sustainable development. Technology is a key driver of innovation and a driver of sustainable business growth [10], [11], and it contributes (both positively and negatively) to the (un)sustainability of socio-technical systems [12]. Significant advances in technologies across the globe, as well as the rate and scope of change of such technological advances, and of their application, pose multiple challenges for individuals, organisations, and society, in respect of the increasing cost, complexity, and risk of technology investments, especially against a background of increasing global competition [11]. An uncontested fact, however, remains that technology, whatever the purpose of using it, has to be managed.

Furthermore, a popular opinion in the literature is that a single discipline is no longer adequate to solve progressively complex (sustainability) problems; and, within the context of socio-technical transitions, researchers urge that further cross-over and integration between disciplines is needed to improve the understanding of and insight into the dynamics of socio-technical transitions, and how such transitions can be fostered, influenced, and even possibly managed [13], [14]. The contribution of inter- and trans-disciplinary research is expected to be significant for numerous contemporary challenges. In addition, the integration of disciplines is expected to open up new paths for innovation, as this would create linkages between established disciplines and identify new opportunities for innovation [7].

This study considers a specific relationship within this technology-social context — namely, the link between technology management and socio-technical transitions. A socio-technical perspective on sustainability is based on the contextual understanding of technology [1]; and, in order to develop, diffuse, and apply technology to foster and facilitate sustainability, technologies and/or technological innovations that promise to contribute to sustainable development have to be managed accordingly. This study thus argues that the exploration and identification of the overlap and integration, or lack thereof, of socio-technical transitions literature and the technology management literature is a vital consideration when the ultimate aim is to facilitate transitions to sustainability, especially given the role of technology in such transitions.

The literature, information, and knowledge tend to be segmented and discipline-specific, making it difficult for experts in a given field or discipline to comprehend the 'big picture' or the direction of knowledge [7]. And when sustainability is considered, it is generally agreed that a holistic systems view of socio-technical systems is required when the transitions of such systems are studied. Scientific research has evolved to be increasingly interdisciplinary over the last couple of decades, which has resulted in an improved fundamental understanding of how to address problems to which the solutions lie outside the boundaries of a single field of research, practice, or discipline [15], [16]. Nevertheless, the constant growth and

[1] http://jeffsachs.org/category/topics/sustainable-development/

[2] http://www.gunterpauli.com/Home.html

evolution of research and knowledge has resulted in the boundaries between disciplines and/or fields of research becoming increasingly unclear, adding to the challenge of delimiting the overview of a specific problem under consideration [7]. Given this, Ittipanuvat *et al*. [7] state that an interfacial layer exists between disciplines and/or fields of research, but that the internal structure of such a layer is often not visible or is unclear. However, it is argued that an investigation into this 'interfacial layer' through bibliometric research or analysis is an effective way to gain insight into the integration of or overlap between disciplines and/or fields of research [17]. A bibliometric analysis is an approach used to extract information about a field (or fields) of research from bibliographic databases, and subsequently to perform qualitative and quantitative analyses to explore the knowledge structure, research trends, emerging areas of research, patterns, and development of research fields, based on the analysis of related published documents — primarily scientific research [18]. Bibliometric research includes the efficient application of information technology to extract, analyse, and interpret useful information from current knowledge databases [7]. Put differently, this form of research investigates information relating to fields of research and/or scientific networks through the use of a number of indicators such as publications, references, authors, keywords, citations, co-citations, authors, author affiliation and geographic location, and related characteristics that could improve our understanding of the landscape of scientific networks [18].

Identifying the areas of integration (and disconnect) between the scientific networks of socio-technical transitions and technology management potential benefits both of these fields of research [19], [20]. The inclusion of sustainability aspects in technology management theories and practices has been argued for. In 2008, Brent and Pretorius [21] concluded that sustainability aspects were not adequately addressed in technology management theories and practices, and subsequently developed a framework that coupled technology management tools and techniques as they relate to sustainable development. And in recent years the discipline of engineering and technology management has increasingly engaged with issues of sustainable development [7], [22]. However, the overlap between and integration of the respective scientific networks of technology management and socio-technical transitions have not been evaluated. The objective of the present paper is thus to investigate and compare the structures of the scientific networks in the technology management (TM) and socio-technical transitions (STT) literature in order to explore the interfacial layer between the two bodies of literature. A subsequent paper aims to identify to what degree these two bodies of literature overlap and integrate concepts, and to what extent the concepts of the two bodies of literature are mutually included in their respective fields.

2 METHODS

The disconnect between the literatures pertaining to technology management and socio-technical transitions is considered in two parts; this paper — *Part 1* — is concerned with the bibliometric analysis (BA) and includes two phases; and the subsequent paper — *Part 2* — deals with the linkage analysis (LA) and includes five phases. An overview of the methodology followed in these papers is shown in Figure 1. Similar approaches have been used throughout the literature [7], [17], [23], [24]. In this study, two different scientific networks are analysed; *Part 1* is concerned with the initial stages of this study in which the scientific networks are analysed individually and then compared across a number of dimensions. The aim of this analysis is to create the academic landscape of each scientific network to improve the understanding of the structure of each network, and how these structures compare. Subsequently, the analysis that evaluates the linkages and integration between the two fields is conducted (*Part 2*). In *Part 1,* the BA is aimed at the collection and comparison of the data concerned with each of the two data sets obtained for the two scientific networks. *Step 2*, the LA, deals with the investigation of the overlap and integration of the two bodies of literature.

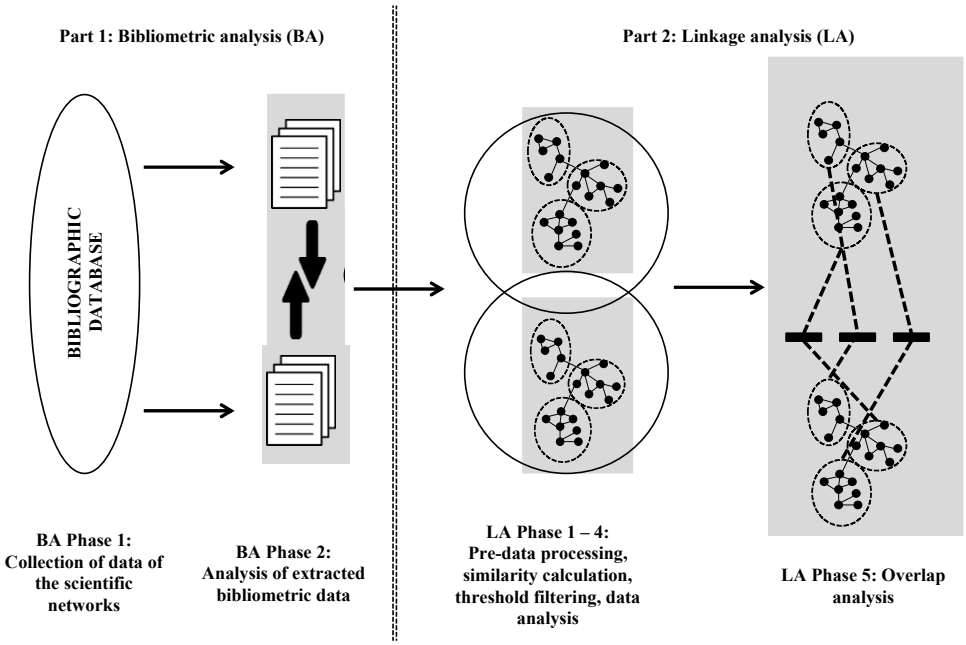


Figure 1: Schematic representation of the methodology

2.1 Bibliometric analysis method

2.1.1 BA Phase 1: Collection of data of the scientific networks

In order to grasp the academic landscape of both technology management and socio-technical transitions, a structured keyword-based search was used to identify and collect documents that constitute the scientific networks of the 'socio-technical transitions' and 'technology management' literature. The BA is based on the approach proposed by Chappin and Ligtvoet [17], who performed a bibliometric analysis of the scientific fields researching socio-technical change that specifically related to socio-technical transitions and transformations. The keyword analysis conducted by Chappin and Ligtvoet [17] was used as the basis of the keyword selection for this research inquiry, but it was adapted to fit this study more specifically. The keywords 'socio-technical transition' and 'technology management' were not used in isolation, but the keyword sets were expanded; the keywords (Table 1) were thus selected to use for the document collection. Table 2 shows the keywords used in the respective sets.

Table 1: Keywords

Keyword	Expanded set of keywords
Socio-technical transition	Sociotechnical transition, socio-technical transformation, sociotechnical transformation, socio-technical change, sociotechnical change
Technology management	Management of technology

Table 2: Keywords used in the respective searches

	Search terms included in set							
	"socio-technical transition"	"sociotechnical transition"	"socio-technical transformation"	"sociotechnical transformation"	"socio-technical change"	"sociotechnical change"	"technology management"	"management of technology"
Socio-technical transitions set	x	x	x	x	x			
Technology management set							x	x
Combined search	x	x	x	x	x	x	x	x

The keywords were searched for in the titles, abstracts, and keywords of documents, restricting the results to all articles published up until the end of 2015 to allow for repeatability. The same 'combined search'

was conducted during the second half of 2018, and only two additional documents ([19], [20], both by the authors of this paper, both published after the end of 2015, and thus not included in the data set) resulted from the combined search. The keywords were used in a number of combinations. All keywords were searched for as phrases in Scopus[3]. The search was done with no other restrictions on publication year, subject area, or document type. A structured keyword-based search was thus used to identify and collect documents, authors, and citations in the fields of 'socio-technical transitions' and 'technology management'. Keywords directly linked to sustainable development and innovation management were deliberately not used in order to let the relevance of technology management and socio-technical transitions to sustainable development and innovation management emerge from the analysis. The identification and delineation of a scientific network by searching the literature databases by keywords is challenging, because the results depend significantly on the selected keywords. To counter this, full transparency about the choices that was made throughout this inquiry is provided.

2.1.2 BA Phase 2: Analysis of extracted bibliometric data

For all the documents identified during Phase 1 of the BA, the data that was extracted from both scientific networks included:

i. Title and keywords;
ii. Authors;
iii. Number of citations;
iv. Source of publication;
v. Mode of publication;
vi. Geographical representation;
vii. Subject area, and;
viii. References/citations.

For the BA of the extracted data, the data listed in i – vii above was used. The references (viii) were used primarily in the linkage analysis (*Part 2*). The results from the two searches were analysed and subsequently compared to gain insight into the bibliometric similarities and differences between the socio-technical transitions and technology management scientific networks. The results from this analysis are discussed in Section 3.

3 BIBLIOMETRIC ANALYSIS: RESULTS AND ANALYSIS

3.1 Overview of the results

An overview of the search statistics is shown in Table 3. The literature search (BA Phase 1) resulted in 331 documents for the socio-technical transition scientific network and 4740 documents for the technology management scientific network. As mentioned earlier, only two articles ([10], [25]) were found to be present in both networks. Also, as stated in Section 2, only two additional documents ([19], [20] – those that were published after the end of 2015 and so were not included in the original data set) considered both technology management and socio-technical transitions. However, owing to this overlap of only two documents, the two sets were expanded to include the references used within each of the two scientific networks. This resulted in the socio-technical transitions set being expanded to include 17 445 references, and the technology management set being expanded to include 112 498 references. The references in the respective sets of documents were primarily used in the linkage analysis in *Part 2*.

Table 3: Search statistics

	Documents in search	Number of references	Total citations	Total unique authors	Total authors
Socio-technical transitions set	331	17 445	6 512	555	716
Technology management set	4 740	112 498	36 331	8 078	8 573
Combined set	2	N/A	N/A	3	3

It is clear that the network of scientific documents in the technology management literature is significantly larger than that for socio-technical transitions. The number of publications per year is shown in Figure 2.

[3] https://www.scopus.com/

It is also clear that the technology management field is an 'older' and more established field of research or discipline than that of socio-technical transitions — not only in that publications concerned with technology management began to appear earlier than those on socio-technical transitions, but also that the frequency of publications began to increase a couple of decades before the frequency of publications concerned with socio-technical transitions began to increase. The total number of citations in the technology management and the socio-technical data sets was 36 331 and 6512 respectively.

The bibliometric analysis was thus based on 5 071 documents (the combined number of documents found in the bibliographic database), and the linkage analysis (*Part 2*) was based on 129 943 references (the combined number of references for the documents found in the bibliographic database).

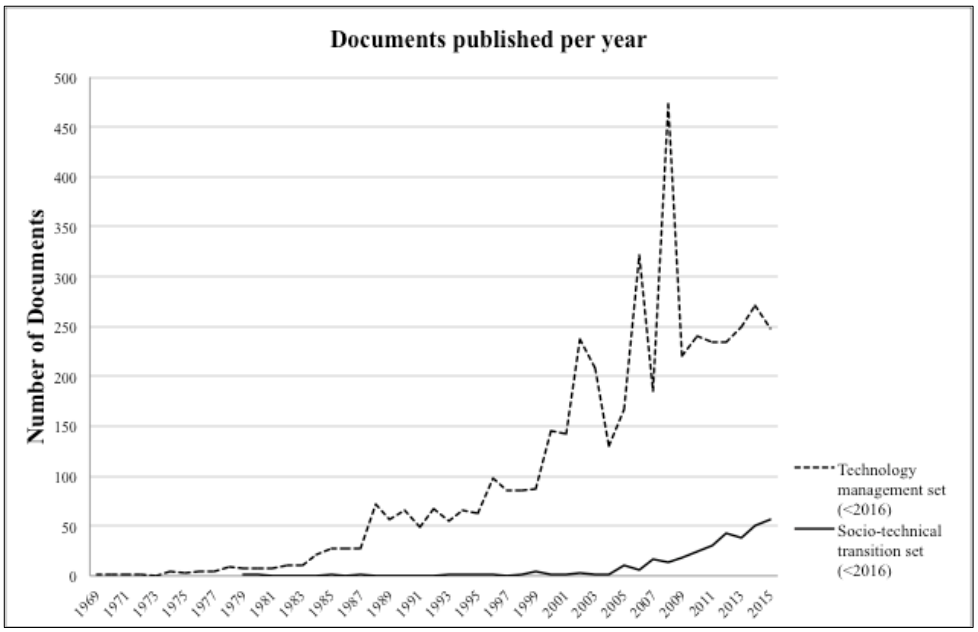


Figure 2: Number of publications per year

The data retrieved from the bibliometric database was subsequently analysed, and various elements were considered and compared across the two scientific networks. These included contributing authors, keywords, title words, sources of publication, subject areas, modes of publication, and geographical representation.

3.2 Key contributing authors

When the authors that contributed to the respective scientific networks were considered, as might be expected, more distinct/unique authors were found in the technology management network than in the socio-technical transitions network (8 087 authors vs 555 authors)[4]. However, the ratio of unique authors per document was similar for both sets of documents: the average number of unique authors for the documents on socio-technical transitions was 1.68, while the average number of unique authors for the technology management documents was 1.70. In addition, the average number of authors per document was also similar between the two sets of documents. For the socio-technical transition documents, there were 2.16 authors per document, while for the technology management documents the average was lower at 1.80 authors per document. These numbers imply that there was not a large difference in the number of co-authors, nor per paper, nor in the number of different authors in the field, when the volume of documents in the respective fields was considered.

Since the primary objective was to investigate the level of integration and overlap between the two identified scientific networks, the authors who contributed to each of the two fields were compared to identify those who contributed to both sets of documents. Aside from the three authors of the two papers

[4] It should be noted that there were inconsistencies in the metadata found in the bibliographic database. However, these inconsistencies were addressed as fully as possible by reviewing the author metadata and combining the metadata that clearly referred to the same author.

that were in both sets of documents (Wells, Lin, and Dolata [10], [25]), and excluding De Kock and Brent [19], [20] — the only two authors who had published articles since the end of 2015 that considered both technology management and socio-technical transitions — an additional 33 authors had contributed to documents in both sets. These authors are shown in Table 4. Interestingly, four of them also featured in the lists of the most prominent authors who had contributed to either the technology management or the socio-technical transition bodies of literature. These authors were, as highlighted in red in Table 4 and Table 5:

1. Prof. Ulrich Dolata (Dolata U. in the tables below) from the University of Stuttgart, Department of Organizational Sociology and Innovation Studies. His key areas of focus include technology, economic sociology and organisation studies, innovation research, technology policy, sociology and political economy of the internet.
2. Prof. Alan Porter ('Porter A.L.' in the tables below) from Georgia Institute of Technology, School of Public Policy. His key areas of research include science, technology, and innovation policy.
3. Prof. Harald Rohracher ('Rohracher H.' in the tables below) from Linköping University, Technology and Social Change (TEMAT) and Department of Thematic Studies (TEMA). His work focuses on a better understanding of the co-evolution of technology and society, as well as strategies to promote socially and environmentally sound technologies, and the consequences of strategies that aim to transition to more sustainable socio-technical systems.
4. Prof. Peter Wells ('Wells P.' in the tables below) from Cardiff Business School. He is a professor of business and sustainability, and the head of the logistics and operations management sections. His research focuses on alternative local economies, the automotive industry, celebrities, wealth and sustainability, corporate strategy, government transport and environment policy, mobility, sustainable business models, and transitions to sustainability.

The most prominent authors in the respective scientific networks, in respect of the number of documents to which each author contributed, are shown in Table 5.

Table 4: Authors who contributed to both scientific networks

Authors					
Bock T.	Dolata U.*	Li Y.	Nam Y.	Rickne A.	Thissen W.
Chang K.-C.	Goulding J.	Lin X.*	Park J.	Rohracher H.	Wang C.-H.
Chang R.	Ho J.C.	Lin Y.-C.	Park S.	Rossini F.A.	Wells P.*
Cooke P.	Kim J.	Liu W.	Phillips F.	Schiavone F.	Yuan J.
Cresswell A.M.	Kim T.	Magnusson T.	Porter A.L.	Smith A.	Zhang J.
De Bruijn E.J.	Lee S.	Martin H.	Rees J.	Taylor R.	Zhao Z.

* Authors who contributed to the two papers that form part of both sets of documents

Table 5: Most prominent authors (number of documents)

Socio-technical transitions set of documents		Technology management set of documents	
Authors	**Number of documents**	**Authors**	**Number of documents**
Geels F.W.	8	Probert D	47
Smith A.	8	Phaal R.	41
Rohracher H.	5	Farrukh C.	24
Shin D.H.	5	Daim T.U.	21
Truffer B.	5	Kocaoglu D.F.	17
Voβ J.P.	5	Pantano E.	17
Wells P.	5	Berg D.	16
Bolton R.	4	Garcia R.	15
Dolata U.	4	Brent A.C.	14
Lopolito A.	4	Schuc G.	14
Markard J.	4	Porter A.L.	13
Morone P.	4	Pretorius L.	13
Morone P.	4	Walsh	13
Newman M.	4	Cunningham S.W.	12
Papachristos G.	4	Einspruch N.G.	11

Table 6 and Table 7 show the most-often-cited documents in the socio-technical transitions and technology management sets respectively. As might be expected, the overlap in respect of authors, focus areas, and sources of publication was limited: the only indication of overlap in the most-cited documents in the respective bodies of knowledge was that there were documents in both sets that were concerned with innovation — i.e., the works of Smith *et al.* [26], Markard and Truffer [27], Enkel *et al.* [28] and Gann and

Salter [29]. However, these research efforts focused on different aspects of innovation in respect of the context and the level and unit of analysis.

Table 6: Most-cited documents in the socio-technical transition set of documents

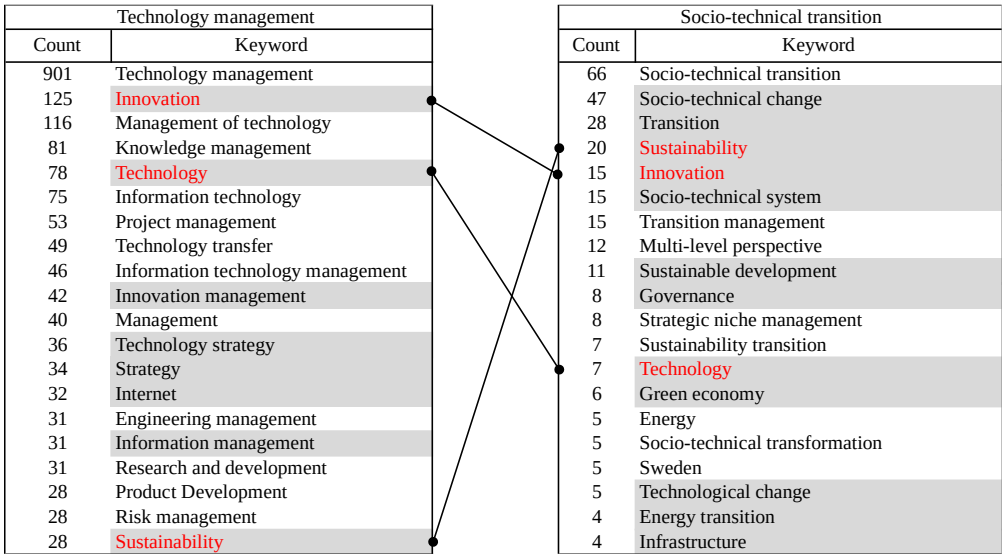
Document title	Author(s)	Publication year	Number of citations*
Typology of sociotechnical transition pathways	Geels, F.W., Schot, J.	2007	1271
The governance of sustainable socio-technical transitions	Smith, A., Stirling, A., Berkhout, F.	2005	773
The multi-level perspective on sustainability transitions: Responses to seven criticisms	Geels, F.W.	2011	507
Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges	Smith, A., Voß, J.-P., Grin, J.	2010	491
Technological innovation systems and the multi-level perspective: Towards an integrated framework	Markard, J., Truffer, B.	2008	415
Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective	Geels, F.W.	2010	398
Governing transitions in the sustainability of everyday life	Shove, E., Walker, G.	2010	292
Can cities shape socio-technical transitions and how would we know if they were?	Hodson, M., Marvin, S.	2010	278
What about the politics? Sustainable development, transition management, and long term energy transitions	Meadowcroft, J.	2009	276
Growing grassroots innovations: Exploring the role of community-based initiatives in governing sustainable energy transitions	Seyfang, G., Haxeltine, A.	2012	254

Table 7: Most cited documents in the technology management set of documents

Document title	Author(s)	Publication year	Number of citations*
A framework for quality management research and an associated measurement instrument	Flynn, B.B., Schroeder, R.G., Sakakibara, S.	1994	1097
Examining the technology acceptance model using physician acceptance of telemedicine technology	Hu, P.J., Chau, P.Y.K., Liu Sheng, O.R., Tam, K.Y.	1999	886
A comprehensive conceptualization of post-adoptive behaviors associated with information technology enabled work systems	Jasperson, J., Carter, P.E., Zmud, R.W.	2005	738
Knowledge and the firm: Overview	Spender, J.-C., Grant, R.M.	1996	670
Open R&D and open innovation: Exploring the phenomenon	Enkel, E., Gassmann, O., Chesbrough, H.	2009	656
Innovation in project-based, service-enhanced firms: The construction of complex products and systems	Gann, D.M., Salter, A.J.	2000	644
Information technology acceptance by individual professionals: A model comparison approach	Chau, P.Y.K., Hu, P.J.-H.	2001	639
Generic knowledge strategies in the U.S. pharmaceutical industry	Bierly, P., Chakrabarti, A.	1996	523
Technologies of humility: Citizen participation in governing science	Jasanoff, S.	2003	513
Investigating healthcare professionals' decisions to accept telemedicine technology: An empirical test of competing theories	Chau, P.Y.K., Hu, P.J.-H.	2002	487

3.3 Keyword analysis

The twenty most-frequently used keywords in both the technology management and the socio-technical transitions scientific networks are shown in Figure 3. The keywords highlight the strong focus on sustainability and sustainable development in the socio-technical transitions set, whereas the focus of the technology management scientific network was mostly on the management of various subjects, as well as on innovation. The keywords shown in red (innovation, technology, and sustainability) are those that were prominent (in the 20 most-frequently used keywords) in both scientific networks. As might be expected, 'technology' is a much more frequently used keyword in the technology management scientific network, and the same goes for 'sustainability' in the socio-technical transitions network. The fact that 'innovation' is the second and fifth most-frequently used keyword in the technology management and socio-technical transitions networks respectively indicated that the literature concerned with 'innovation studies' (or just 'innovation') was where these two bodies of literature overlapped. However, the keywords highlighted in grey are keywords that were present in both sets, although not used as frequently (i.e., not in the 20 most-frequently used keywords).



Technology management	
Count	Keyword
901	Technology management
125	Innovation
116	Management of technology
81	Knowledge management
78	Technology
75	Information technology
53	Project management
49	Technology transfer
46	Information technology management
42	Innovation management
40	Management
36	Technology strategy
34	Strategy
32	Internet
31	Engineering management
31	Information management
31	Research and development
28	Product Development
28	Risk management
28	Sustainability

Socio-technical transition	
Count	Keyword
66	Socio-technical transition
47	Socio-technical change
28	Transition
20	Sustainability
15	Innovation
15	Socio-technical system
15	Transition management
12	Multi-level perspective
11	Sustainable development
8	Governance
8	Strategic niche management
7	Sustainability transition
7	Technology
6	Green economy
5	Energy
5	Socio-technical transformation
5	Sweden
5	Technological change
4	Energy transition
4	Infrastructure

Figure 3: Most-frequently used keywords

3.4 Sources of publication and subject areas

Considering the sources of publication, six journals — *Environmental Innovation and Societal Transitions* (*EIST*), *Technological Forecasting and Social Change* (*TFSC*), *Energy Policy*, *Research Policy*, *Environment and Planning*, and *Technology Analysis and Strategic Management* (*TASM*) — emerged as the leading outlets for documents published on socio-technical transitions. The ten top sources of the socio-technical transitions documents accounted for 31% of the socio-technical transitions network. The six leading sources for technology management documents included the *Portland International Conference on Management of Engineering and Technology* (*PICMET*) proceedings, the *International Journal of Technology Management* (*IJTM*), *IEEE Transactions on Engineering Management*, *Technovation*, *IEEE International Engineering Management Conference*, and *TFSC*. The ten top sources of technology management documents accounted for 18% of the documents in the technology management network. When compared with the 31% of the socio-technical transitions documents published in the six top socio-technical transitions sources, it is clear that the technology management literature was published across a wider range of sources, implying that the socio-technical transitions network at this stage was a more concentrated field of research. The only source that was among the most prominent sources of publication for both scientific networks was *TFSC*. The only other journal that was among the twenty top sources in both fields was *Technology Analysis and Strategic Management*. In the top one hundred sources of both fields, twelve sources were present in both sets, from which one could infer that there was no significant overlap between these two fields of literature when the sources of publication were considered.

The key journals provided an indication of the broader scholarly communities within which technology management and socio-technical transitions are embedded, or to which they are related. It was evident that both fields of literature are trans- and multi-disciplinary. However, the scholarly communities for the

respective fields differ quite significantly. These include, for technology management, the management of engineering, science, and technology, decision-making or policy formulation for R&D, technological innovation, commercial utilisation of technology, as well as technological forecasting and planning tools for technology management as they relate to society, the environment and technological factors. The focus of the socio-technical transitions document sources included innovation studies, sustainable development, environmental studies, technological factors (with a specific focus on energy within sustainable development), and policy studies.

From another perspective, the various subject areas that the documents on socio-technical transitions focused on, in comparison with those that the technology management documents focused on, were considered by looking at the percentage of documents that were concerned with any specific subject areas. It should be noted that, in most cases, documents addressed more than one subject area. From the analysis shown in Figure 4, it is evident that there was an overlap in the subject areas that the two scientific networks addressed. Three of the five most-frequently addressed subject areas were present in both fields; these 'business management and accounting', 'engineering', and 'social sciences'. The most popular subject area addressed in the technology management documents was 'business, management, and accounting'; but this was the third most-frequently addressed subject area in the socio-technical transitions scientific network. In addition, 'engineering', which was the second most-frequently cited subject area for technology management, was the fifth most-cited subject area for socio-technical transitions. The two most-frequently addressed subject areas in the socio-technical transitions set of documents were 'social-sciences' and 'environmental science'. Figure 5 shows the extent of the overlap in the subject areas addressed. It can be inferred from this figure that the extent to which the literature concerned with socio-technical transitions ventured into the subject areas that are traditionally regarded as related more to technology management were more extensive than the extent to which the literature concerned with technology management ventured into subject areas that are traditionallyregarded as related more to socio-technical transitions.

	Technology management set of documents		
	Subject Area	Number of papers	%
1	Business, Management and Accounting	2146	45,3%
2	Engineering	1973	41,6%
3	Computer Science	1038	21,9%
4	Decision Sciences	902	19,0%
5	Social Sciences	477	10,1%
6	Medicine	284	6,0%
7	Economics, Econometrics and Finance	190	4,0%
8	Chemical Engineering	146	3,1%
9	Environmental Science	126	2,7%
10	Mathematics	123	2,6%
11	Materials Science	87	1,8%
12	Earth and Planetary Sciences	77	1,6%
13	Biochemistry, Genetics and Molecular Biology	69	1,5%
14	Psychology	69	1,5%
15	Energy	67	1,4%
16	Health Professions	49	1,0%
17	Agricultural and Biological Sciences	47	1,0%
18	Nursing	47	1,0%
19	Physics and Astronomy	40	0,8%
20	Multidisciplinary	33	0,7%
21	Arts and Humanities	25	0,5%
22	Undefined	21	0,4%
23	Chemistry	12	0,3%
24	Pharmacology, Toxicology and Pharmaceutics	9	0,2%
25	Veterinary	5	0,1%
26	Immunology and Microbiology	3	0,1%
27	Neuroscience	1	0,0%

STT set of documents		
Subject Area	Number of papers	%
Social Sciences	162	48,9%
Environmental Science	119	36,0%
Business, Management and Accounting	77	23,3%
Energy	56	16,9%
Engineering	51	15,4%
Computer Science	44	13,3%
Decision Sciences	35	10,6%
Economics, Econometrics and Finance	17	5,1%
Psychology	17	5,1%
Arts and Humanities	14	4,2%
Earth and Planetary Sciences	6	1,8%
Medicine	4	1,2%
Multidisciplinary	4	1,2%
Agricultural and Biological Sciences	3	0,9%
Biochemistry, Genetics and Molecular Biology	3	0,9%
Physics and Astronomy	2	0,6%
Chemical Engineering	1	0,3%
Materials Science	1	0,3%
Mathematics	1	0,3%

Figure 4: Subject areas

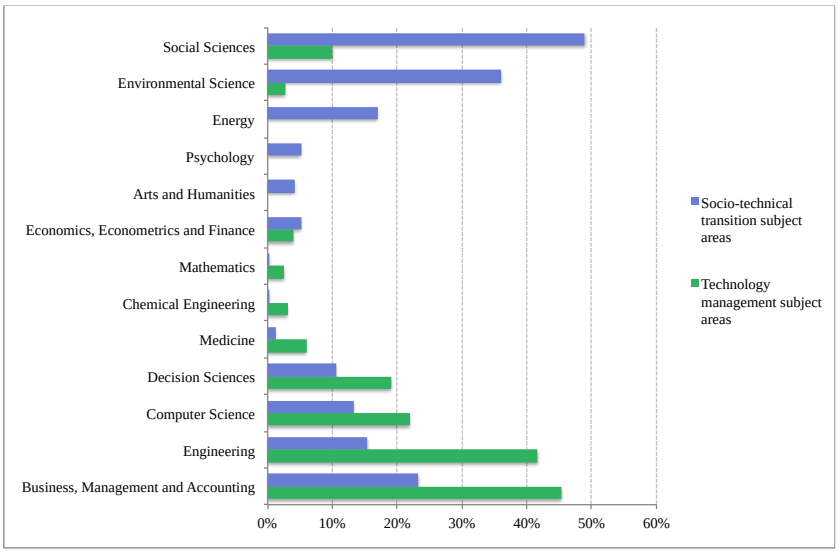


Figure 5: Subject area overlap comparison

3.5 Mode of publication

Looking at the mode of publication, the two key differences between the two bodies of knowledge were: i) the technology management documents were better represented across a wider range of document types, and ii) there was a significant difference in the number of academic conference papers and journal articles published in the two scientific networks: 71.9% of the documents concerned with socio-technical transitions were published as journal articles and 12.7% as conference papers, whereas 45% of the technology management documents were journal articles and 41.8% were conference papers. This might be attributed to the socio-technical transitions field being relatively new, with the number of conferences that cater for research done on socio-technical transitions not being as established as those for technology management. Interestingly, there was not a significant difference in the percentage of books between the two fields: 1.2% and 1.7% for socio-technical transitions and technology management respectively. Figure 6 shows the respective modes of publication.

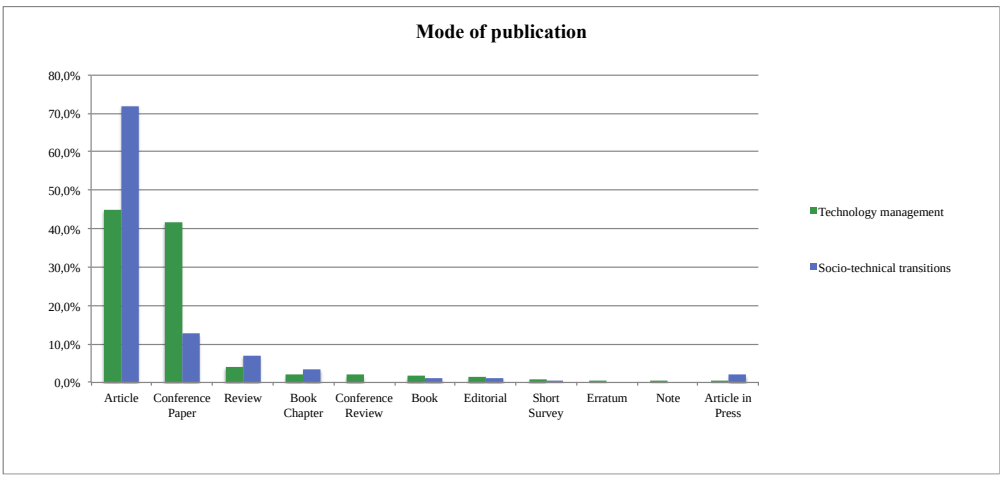


Figure 6: Respective modes of publication

3.6 Geographical representation

In geographical terms, the five top countries with research competency in the technology management field were the United States (US), the United Kingdom (UK), China, Japan, and Germany. It is notable that a single country — the US — led the others, with more than a quarter of the documents in the technology management scientific network having an affiliation with the US. When all European countries were considered together, the research competency in Europe was equivalent to that of the US for technology

management. When the research competency per country for the socio-technical transitions network was considered, the UK led the others, with a quarter of the documents in the socio-technical transition network having affiliations with that country. When all of the countries were considered, more than 67% of the documents in the socio-technical transitions network had a European affiliation, while only 3.8% of the documents in this network had affiliations with BRICS[5] countries. This reinforces the statement made by Lachman [30], who argues that the approaches that have been developed to study socio-technical transitions are heavily flavoured by the context of developed countries — the environment within which they were developed — and thus might be less suitable for contexts such as developing countries. In addition, Tigabu *et al*. [31] argue that most research concerned with technological innovation systems (TIS) and transitions has been conducted in highly developed countries, and the applicability of approaches such as TIS to developing countries is still unclear. Markard *et al*. [5] added to these arguments by stating that there is a clear 'European bias' in the current state of the socio-technical transitions field, which is to be expected, given the location of the researchers contributing to this field of research. Table 8 shows the geographical representation of the respective scientific networks.

Table 8: Geographical representation of the respective scientific networks

Technology management set of documents		**Socio-technical transitions set of documents**	
Geographical area	**% of documents**	**Geographical area**	**% of documents**
United States (US)	26%	United Kingdom	25%
United Kingdom (UK)	6%	United States	12%
China	5%	Netherlands	11%
Japan	4%	Germany	6%
Germany	4%	Sweden	5%
Combined for European countries	25.8%	Combined for European countries	67.4%
BRICS countries	12.4%	BRICS countries	3.8%

4 DISCUSSION

The bibliometric analysis highlights the most prominent areas of overlap, although they are limited, between the technology management and the socio-technical transitions' bodies of literature. An overlap of two documents was found between the two bodies of literature (i.e., the work of Dolata [10] and Wells and Lin [25]) — the first quantitative indication that there was a disconnect between these two bodies of literature. These two documents, found in both sets of literature, focused on the changes in socio-economic structures, institutions, and actors under the influence of technology, and how they react to technology-induced pressures to change and to processes of change outside the traditional context of technology policy and management respectively, thus highlighting that both consider the management of technology in the context of change in socio-technical systems, but do not consider the integration or overlap of technology management and socio-technical transitions *per se*.

It was found that 36 unique authors (out of a possible 8 633) contributed to both bodies of literature, indicating that a small number (0.004%) of authors conducted research that was applicable to both bodies of literature. Interestingly, four out of the 36 unique authors who contributed to both bodies of literature were also among the most prominent authors in terms of the number of documents contributed to the two respective bodies of literature (refer to Table 4 and
Table 5). When considering the focus areas of these authors, it is clear that their areas of research were in line with the areas of overlap found in the bibliometric analysis — namely, technology, innovation, and sustainability. Other prominent areas in the research of these researchers that were not noticeable from the bibliometric analysis, but were evident from the linkage analysis performed and discussed in the next paper (*Part 2)*, were the focuses on economics and policy [32].

From the keyword analysis, it was evident that the three areas where the technology management and socio-technical bodies of literature overlapped were innovation, technology, and sustainability. However, the prominence of these three areas in the respective fields differed. For example, 'sustainability' was the fourth most prominent keyword in the socio-technical transitions body of literature, but only the twentieth most prominent keyword in the technology management body of literature. 'Technology' was ranked higher in prominence in the technology management body of literature (fifth) but only 13th in the socio-technical transitions body of literature. The keyword analysis indicated that innovation was an area that ranked

[5] BRICS is the acronym for an association of five major emerging economies: Brazil, Russia, China, India, and South Africa.

relatively high in both bodies of literature: second in the technology management body of knowledge, and fifth in the socio-technical transitions body of literature; thus it could said to represent the most significant overlap.

The only two sources of publications that were prominent in both bodies of literature were the journals *Technological Forecasting and Social Change* (*TFSC*)[6] and *Technology Analysis and Strategic Management* (*TASM*)[7]. *TFSC*'s focus was on technological forecasting and future studies as planning tools, since they interrelate social, environmental, and technological factors. The focus of *TASM* was on linking the analysis of science, technology, and innovation with the strategic needs of policy-makers and management. Here, it was evident that both technology management and socio-technical transition scholars, in addition to what has already been highlighted as overlaps between the two bodies of knowledge, engaged in inter-, trans-, and multidisciplinary research, with a strong focus on the role of technology in strategy and policy. This highlighted the difference, generally speaking, in the level and unit of analysis of these two bodies of literature.

Given the nature of both technology management and socio-technical transitions — the inter-, trans-, and multidisciplinary nature of both these disciplines — it is not surprising that there was a seemingly significant overlap in the subject areas that were addressed. However, there was a difference in the order of prominence in respect of the number of papers that were concerned with the subject areas. Business, management and accounting, social sciences, and engineering were the five top subject areas for both bodies of literature; environmental science was the second most prominent in the socio-technical transitions body of literature, but only the ninth most prominent in the technology management body of literature — which was in line with the findings of De Kock and Brent [19] that, to date, technology management has not turned sufficiently towards dealing with environmental challenges. From the analysis of the subject areas, and the overlap in such areas, it was then inferred that the extent to which the literature concerned with socio-technical transitions had ventured into the subject areas that are traditionally regarded as related more to technology management was more extensive than the extent to which the literature concerned with technology management had ventured into subject areas that are traditionally considered to be related more to socio-technical transitions (see Figure 5).

When the geographical representation of the two bodies of literature was considered, it became clear that both disciplines were strongly linked with North America and with European countries, with significantly less representation in countries with developing or emerging economies. A number of researchers (Lachman [30], Tigabu *et al*. [31], Markard *et al*. [5]) have raised concerns about the lack of representation in the research of issues such as socio-technical transitions and technology management from a non-Western perspective — a point that often raises questions about the applicability of developed concepts to other contexts.

5 CONCLUSION

In this paper, a bibliometric analysis has been used to elucidate the apparent disconnect between the literature on socio-technical transitions and technology management respectively. Throughout this paper, a number of areas of overlap are identified. However, the only key area of overlap that has emerged from this analysis is that of innovation. Yet there is evidently no concrete evidence of integration or significant similarity in the foundational concepts used in both bodies of literature. It is thus proposed that this study be enriched by a systematic in-depth exploration of the literature bases (i.e., the references used by the respective bodies of literature) in order to develop insights into the concepts that underpin the respective fields of research, and ultimately to confirm or refute the highlighted disconnect between socio-technical transitions and technology management.

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[6] https://www.journals.elsevier.com/technological-forecasting-and-social-change
[7] https://www.tandfonline.com/loi/ctas20

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