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Developing a sustainability implementation framework: insights from academic research on tools, initiatives and approaches

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Abstract

Sustainability has been proposed to address societal challenges. A number of efforts have been undertaken to implement sustainability, particularly through frameworks such as tools, initiatives and approaches (TIAs). Most of the research on the implementation efforts has been in the corporate context. This paper is aimed at analysing the implementation of TIAs in academic research. A bibliometric analysis of twenty TIAs during the period 1961–2020 was carried out to analyse their implementation in academic research. The results highlight that there has been research published on all the TIAs analysed. The TIAs have a better balance and interrelations between the sustainability dimensions in their implementation than in the theory. The results show that for a better implementation of TIAs in academic research it is necessary to address sustainability dimensions (economic, environmental, social, and time) in a holistic and balanced way considering alignment of general and specific efforts, i.e. TIAs, and congruence (linking 'theory' and 'implementation'). The results were integrated to propose a 'Sustainability Implementation Framework' (SIF), which is divided into three levels (i.e., Initiatives, Approaches, and Tools). The TIAs implementation should follow more strictly the definitions, or, perhaps, the TIAs definitions should be redefined to encompass the insights from their implementation.

Keywords Bibliometric analysis · Tools, initiatives, and approaches · Corporate social responsibility · Corporate sustainability · Green chemistry · Sustainability implementation framework

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1 Introduction

Sustainability has been proposed as a way to address the challenges (e.g. climate change, poverty and literacy) posed within the economic, environmental, social, and time dimensions (Brundtland, 1987), as well as their complex dynamic interrelations (Lozano, 2008). For sustainability to address such challenges, it is necessary to address them through a holistic perspective (see Elkington, 1998), i.e. their integration and the interrelations (Dalal-Clayton et al., 2002; Langer & Schön, 2003). Such complexities and broadness of the sustainability concept raise a number of challenges for its implementation (Dyllick & Hockerts, 2002; Hussey et al., 2001; Lozano, 2008), i.e. the translation of a concept, such as sustainability, from 'theory' (i.e. definitions) into 'action' (i.e. providing results and solutions) (Chofreh & Goni, 2017; Hugé et al., 2013).

A number of efforts have been developed to help implement sustainability, e.g. in organisations (Corsi & Arru, 2020; Hörisch et al., 2015; Lozano, 2020); policy design (Nadin, 2001); and, academic research (Hallstedt & Nylander, 2019; Hugé et al., 2015). Two positions can be discerned in sustainability implementation: (1) 'implementation frameworks'; and, (2) tools, initiatives and approaches (TIAs).

Sustainability implementation frameworks are aimed at managing a complex topic in conceptual structure by providing a way to understand the active (and iterative) process through which desired objectives are achieved (Saluja et al., 2017) by promoting a multi-tiered implementation (e.g. model or a system) of the whole process (Ahmed & Sundaram, 2012). Two implementation frameworks can be found to provide general guidance; a framework divided into indicators, product-related assessment, and integrated assessment tools (Ness et al., 2007); and, a hierarchical classification of sustainability terms and their relationships by using a systematic approach (Glavič & Lukman, 2007).

The TIAs focus on activities and address the 'Approaches' and 'Sub-systems' categories proposed by Glavič and Lukman (2007). The TIAs have been used mainly in the corporate context (see Dalal-Clayton & Bass, 2012; Glavič & Lukman, 2007; Lozano, 2020; Ness et al., 2007; Robèrt et al., 2002). There have been many peer-reviewed publications on the use of the TIAs during the last five decades; however, there is limited research on how to translate 'theory' into 'implementation' for tackling sustainability in academic research[1] (Chofreh & Goni, 2017; Moullin et al., 2020).

This paper is aimed at analysing the implementation of TIAs in academic research and compare this against the TIAs 'definitions'. The paper is structured in the following way: Sect. 2 discusses the implementation of these tools in academic research, Sect. 3 presents the methods, Sect. 4 provides results, Sect. 5, the discussion, and Sect. 6, the final remarks.

2 A review of the TIAs implementation in academic research

A large number of TIAs have been developed, mainly by and for corporations, to better implement sustainability within their systems (Lozano, 2012a, 2012b, 2020), with comprehensive lists (see Dalal-Clayton & Bass, 2012; Glavič & Lukman, 2007; Hoogmartens et al., 2014; Ness et al., 2007; Robèrt, 2000; Robèrt et al., 2002). Some studies have

[1] Academic research is conducted within a higher education institution and ranges from fundamental research to applied (Waas et al., 2010).

proposed classifications; into sustainable systems, sub-systems, approaches, and principles (Glavič & Lukman, 2007) and, indicators or indices, product-related assessment, and integrated assessment tools (Ness et al., 2007). Other studies have focused on one or two TIAs (Ahi & Searcy, 2015; Gunarathne et al., 2021; Rex & Baumann, 2007), and while others have considered multiple TIAs (Glavič & Lukman, 2007; Lozano, 2020; Robèrt, 2000; Robèrt et al., 2002). Limited, yet increasing, research has provided empirical results on the TIAs' use, ranging from more general (approaches) to more particular (tools), in the corporate context (Lozano, 2020).

Although many TIAs stress the importance of integrating the sustainability dimensions (see Ness et al., 2007), the majority of the TIAs have focused on the environmental and economic perspective (Atkinson et al., 2000; Lozano, 2012a, 2012b) based on their definitions (i.e. 'theory'), such as eco-efficiency, aimed at assessing economic and environmental impacts for processes and products (OECD, 1998), and Circular Economy (CE), which links the economic and environmental dimensions (European Commission, 2015). Table 1 summarises the TIAs list provided by Lozano (2020) with its definition, and the sustainability dimensions each one addresses.

TIAs can help to assess and monitor changes associated with strategies and efforts for implementing sustainability, which can guide decision-making and policy development (Lozano, 2020). Some TIAs have attracted more attention from policymakers (e.g. industrial ecology has potential for US environmental policy (Thomas et al., 2003) and Circular Economy has been used as a product policy framework in the European context (European Commission, 2020)).

The majority of TIAs have been analysed on a conceptual level and in case studies (Corsi & Arru, 2020; Windolph et al., 2014) but only a few studies analyse their implementation (for companies), e.g. TIAs have better implementation results when combined (Lozano, 2020), and their effective use can reduce environmental impacts (Hörisch et al., 2015). Some efforts have been undertaken to assess the interlinkages among some TIAs in companies, including the analysis of how companies adopt the CE principles in cleaner production processes in the regional context (Aranda-Usón et al., 2020) and the interactions between three tools, where it was found that their methodologies are similar enough to be used in a complementary manner (Hoogmartens et al., 2014).

Although there has been considerable research on each of the TIAs published in the literature (Corsi & Arru, 2020), there has been limited efforts on the implementation of TIAs in academic research. This includes descriptive approaches by using bibliometric methods (Meseguer-Sánchez et al., 2021; Ye et al., 2020), or a limited number of tools, e.g. the evolution of the research output of green chemistry that has established it as a research discipline (Dichiarante et al., 2010), and the use of TIAs in academic research to foster their implementation (Corsi & Arru, 2020; Windolph et al., 2014).

3 Methods

A bibliometric analysis was carried out to analyse the implementation of TIAs in academic research. For the bibliometric analysis, the following steps were followed in this study: (1) Formulation of a search strategy to identify the output of each tool and data collection; and, (2) Development of bibliometric indicators.

The TIAs selected for this study are those proposed by Lozano (2020) with the difference of grouping the 'Sustainability reporting' (SR) and 'Environmental Management

Table 1 List of tools, initiatives and approaches (TIAs) with acronyms, definitions, and sustainability dimensions

TIA	Acronym	Definition	Sustainability dimensions
Circular economy	CE	CE is 'closing loops ' through different types and levels of recovery (Yong, 2007; Yuan et al., 2006) by transforming material into useful goods and services through resource efficiency (Klettner et al., 2014; Webster, 2013)	Environmental; economic
Cleaner production	CP	CP is the continuous use of integrated preventive strategies to process products and services, utilising raw materials, for example, energy and water, efficiently to reduce waste at source, and minimising risks to the environment and society (DeSimone & Popoff, 2000)	Environmental; economic
Corporate citizenship	CC	CC is a concept where corporations have social rights and responsibilities to their stakeholders beyond wealth maximisation (e.g. compliance with all laws and regulations) (Carroll, 1998; Leisinger, 2003; McIntosh et al., 1998)	Environmental; economic; social
Corporate social responsibility	CSR	CSR is 'the continuing commitment by business to behave ethically and contribute to economic development while improving the quality of life at the workplace and workers' families as well as the local community and the society at large' (Holme & Watts, 2000)	Environmental; economic; social
Corporate sustainability	CS	In order for a company to become more sustainability orientated, it should engage in changes that include the introduction of resource-efficient technologies, sustainability reporting schemes, and provide sustainable products, services, and product–service combinations (Siebenhüner & Arnold, 2007)	Environmental; economic; social
Design for the environment	DESIGN	DESIGN, also known as eco-design, refers to the inclusion of environmental factors and considerations (such as material elimination or substitution, process optimisation, energy reduction, and product reuse) (DeMendonça & Baxter, 2001)	Environmental; economic
Eco-efficiency	ECO	ECO's aim is to link environmental and business excellence, that is, making profits by using fewer natural resources, with less waste, and emissions within the earth's carrying capacity (DeSimone & Popoff, 2000; Ekins, 2005; Hamann, 2003)	Environmental; economic
Ecolabelling	ECOL	ECOL is based on a market approach to the protection of the environment (Hale, 1996; OECD, 1997)	Environmental; economic
Environmental management systems	EMS	EMS are administrative tools aimed at assessing the environmental impact of the operations of organisations, mainly corporations, and in improving their environmental performance (Robèrt, 2000)	Environmental

Table 1 (continued)

TIA	Acronym	Definition	Sustainability dimensions
Factor X	FX	FX refers to the eco-efficiency initiatives Factor 4, Factor 5, Factor 10, and Factor 20, developed by the Wuppertal Institute (Robèrt, 2000; Weizsäcker et al., 1998)	Environmental; economic
Green chemistry	GCHEM	GCHEM is aimed at preventing waste before it is ever formed by considering the environmental impact or potential impact of a product or process (Anastas & Warner, 1998)	Environmental
Green marketing	GMARK	GMARK involves 'marketing activities which attempt to reduce the negative social and environmental impacts of existing products and production systems, and which promote less damaging products and services ' (Peattie, 2001), that is, to shape consumer requirements and provide consumers with appropriate choices (Sheth & Parvatiyar, 1995)	Environmental
Industrial ecology	IE	IE refers to the restructuring of industry in the form of an ecosystem with materials (including raw materials and wastes) flowing through interconnections of production processes (Ehrenfeld, 2004; Isenmann, 2003; Lowenthal & Kastenberg, 1998)	Environmental
Integrated management system	IMS	IMS is an approach to manage processes or activities that transform inputs of resources into a product or service, which meet an organisation's objectives and equitably satisfy the stakeholders' quality, health, safety, environmental, security, ethical or any other identified requirement (Jørgensen et al., 2006; Olaru et al., 2014)	Environmental; economic; social; time
Life cycle assessment	LCA	LCA is evaluation of all processes in the life cycle of a product or service, from downstream (i.e. extraction) to upstream (i.e. disposal), including use (DeSimone & Popoff, 2000; Holliday et al., 2002; Robèrt, 2000)	Environmental; time
Sustainability reporting	SR	SR is a voluntary activity with two general purposes: (a) to assess the current state of an organisation and (b) to communicate to stakeholders the efforts and progress in the economic, environmental, and social dimensions (Dalal-Clayton et al., 2002)	Environmental; economic; social; time
Sustainable supply chain	SSCHAIN	SSCHAIN deals with the planning, execution, and control by integrating economic, environmental, and social issues to improve the long-term performance of an individual company and its supply chain (Stindt, 2017)	Environmental; economic; social

Table 1 (continued)

TIA	Acronym	Definition	Sustainability dimensions
Sustainable responsible investment	SRI	SRI is aimed at integrating environmental, social, and governance criteria into the investment decision-making process (Chava, 2010; Cheung, 2011)	Environmental; economic; social
Natural Step	NAT	NAT is an international educational organisation dedicated to accelerating society's movement towards sustainable development (Robèrt et al., 2002; Williard, 2002), with a framework to aid in this transition (Robèrt, 2000)	Environmental; social; time
Triple bottom line	TBL	TBL focuses on incorporating environmental and social performance indicators, while complementing and balancing the economic indicators into company management, measurement, and reporting processes (Atkinson, 2000; Elkington, 1997; Frankental, 2001; Wilenius, 2005)	Environmental; economic; social

System' (EMS) ones,[2] complemented with the sustainability dimensions (environmental, economic, social, and time) that are defined based on their definition ('theory'), partially based on Lozano (2012b) (complete list in Table 1).

The data required for bibliometric analyses were gathered between mid-November and mid-December 2020 from Clarivate Analytics' Web of Science (WoS) Core Collection (SCI, SSCI, A&HCI). WoS is one of the most well-known multidisciplinary databases with a long and constant coverage of high-quality papers, which is widely used in bibliometric analysis (Mongeon & Paul-Hus, 2016). In this study, different search strategies have been defined for each one of the TIAs (more information on the strategies used in Table S.1). The search was done in the topic field (title, abstract, and keywords) in order to capture all the output of each TIA. All types of documents in WoS were considered, and no temporal limitation once included. Once the data was collected, the following indicators were analysed for the final dataset:

(1) Analysing research patterns.
   - Yearly trend of each TIA.

(2) Identifying 'hot topics' on each TIA.
   - Keywords burst citation. Burst detection is an analytic method to find articles that receive particular attention from the related scientific communities in a certain period of time. This assess the degree of citation intensity for a given reference and keyword. The sudden increases in the usage frequency of keywords (burst strength) based on the citations were identified by using Kleinberg's algorithm to determine the level of 'hotness' of the topics of each TIA in academic research (see Kleinberg, 2003).

(3) Identifying interrelations between the TIAs.
   - Co-occurrence of the keywords assigned to each paper using the VOSviewer tool[3] to identify thematic clusters between the TIAs (higher level) within the scientific landscape. The nodes indicate the number of documents, whilst the co-occurrence links identify inter-keyword relationships and a sign of affinity and their thickness, shows the intensity. In addition, a normalisation method used was the Ling/Long modularity (see Chen, 2016) and different parameters of each cluster were extracted (e.g. link strength_{avg}, year_{avg}).
   - References and keywords co-citation cluster analysis is used to detect subtopic specialties (lower level) of each TIA with CiteSpace software.[4] G-index was used to detect the different specialties (see Eggue, 2006) used for node selection that accounts for the citation values of the articles. A correction factor of 5 was applied and the co-citation values were normalized using the cosine index, and the edges were pruned from the network with the pathfinder algorithm. This correction factor provided better visualization results (a number of comprehensive categories). The labels of each cluster were determined mainly by using the logarithm log-likelihood

[2] For this paper 'Sustainability Reporting' (grouping 'Sustainability reporting (GRI report)'; 'Sustainability reporting (AA1000)'; 'Sustainability reporting (ISO 26000)' and 'Sustainability reporting (SA8000)') and 'Environmental Management System' (constituted by 'Environmental Management Systems (EMAS)' and 'Environmental management systems (ISO 14000 series)') were integrated into one group.

[3] VOSviewer version 1.6.16 was used in this study.

[4] CiteSpace version 5.7.R2 was used for the analysis.

ratio (LLR), which assesses the strength of the bond between the term and the cluster, by considering the abstract text information (see Chen, 2016 for more details). Where there was overlap between the names within the same TIA, the Latent Semantic Indexing (LSI) algorithm was used. With the subtopics identified, a chord diagram was used, which represents connections between the different TIAs.

(4) Developing a sustainability implementation framework:

- The results were integrated to develop an implementation framework for academic research to provide an illustrative overview of these findings. The framework helps to summarize each TIA and discusses its main contributions in combination with the sustainability dimensions and their implementation. To analyse the implementation, the framework relates the TIAs in 'theory' (based on their conceptual definitions) and their 'implementation' (use in academic research). Each subtopic of the TIAs was classified in each sustainability dimension (Environmental; Social; Economic),[5] according to the main focus of sustainability. Some subtopics may be more nuanced and can be less easy to delineate, e.g. sustainability reporting (SR) can be divided into the four dimensions (environmental, social, economic and time). Finally, how the different TIAs might relate to each other is discussed and how the framework might be applied to current research.

3.1 Method limitations

Some of the limitations of this study include the use of the keywords for selecting each one of the tools, which conflicts with what is research '*on*' and '*related*' to each TIA and other studies that might presumably include '*buzzwords*''. Once the documents were collected, a validation procedure was conducted to clean the data. Another limitation was the under-representation of other related published works by considering only the Web of Science (WoS) database, which may be indexed in other scientometric databases (e.g. Scopus, Google Scholar, Microsoft Academic, and Dimensions). Additionally, WoS does not cover all academic fields equally, and it is biased towards papers published in English. The methodology proposed may not necessarily capture the complete panorama of research related to each TIAs. Despite that all types of publications from WoS were included in the three databases from the Core Collection, some other typologies of interest (e.g. sustainability reports, grey literature) were not captured.

4 Results

This section presents a descriptive analysis of the research output results for each TIA, divided into scientific output and evolution; hot topics; and interrelations between the TIAs (between TIAs and within their subtopics).

4.1 Research output

A total of 73,672 records (all types of documents considered) were retrieved from WoS through different search strategies based on relevant terms identified from the literature.

[5] For the sake of simplicity, time dimension was not considered for the analysis.

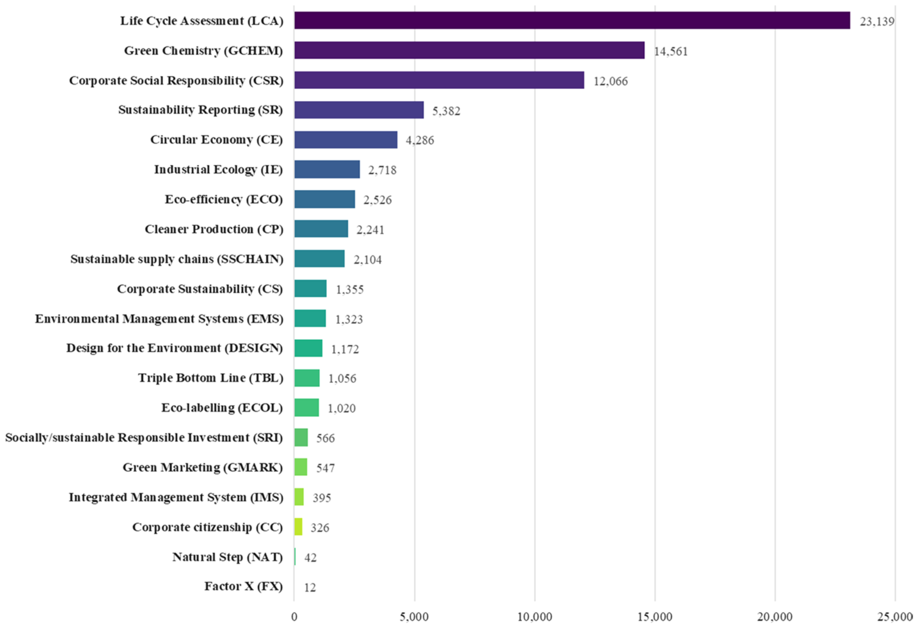

Fig. 1 Scientific output of TIAs retrieved from Web of Science (WoS) (1961–2020)

Figure 1 shows the total number of documents retrieved from the different TIAs (no temporal limit is included). LCA presents the highest number of documents ($n=23{,}139$), followed by GCHEM ($n=14{,}561$) and CSR ($n=12{,}066$) which suggests the TIAS had research interest whereas others (e.g. FX and NAT) scarcely present scientific output. CSR and SR, which are at the top position (3rd and 4th) by output, also coincide with the most widely known TIAs by companies, whereas NAT and FX also appear as the lesser known tools and with less scientific output.

Figure 2 shows the evolution of the number of documents by year of publication (since 1987) of all TIAs. The TIAs were ranked by their total output, according to Fig. 2, where darker colours are associated with the highest output and lighter colours with the lowest. Some TIAs' output were found in early literature (in the sixties) such as LCA, IMS, and CSR. Other TIAs, such as CS, SSCHAIN, and FX, were more recent and had output since the 2000s. As a general tendency, all TIAs' output has a exponential growth tendency over time, with some exceptions (e.g. NAT, CC, and FX). These last ones might be associated with a scarce and discontinuous number of documents over time, i.e. the maximum number of papers in FX in 1 year is 7. The ones that presented a major growth during the period is CE (31.37), CS (29.53), GCHEM (27.98), SSCHAIN (27.89), and TBL (26.65), while others present a lower growth i.e., FX (0), NS (3.06), and CC (6.72). This shows that most of the TIAs have had the time to be implemented in academic research.

4.2 Identifying 'hot topics' on each TIA

Table 2 lists the keywords with the strongest citation bursts, which represent the TIAs that have received increasing interest (based on citations) since the late 1980. In the period

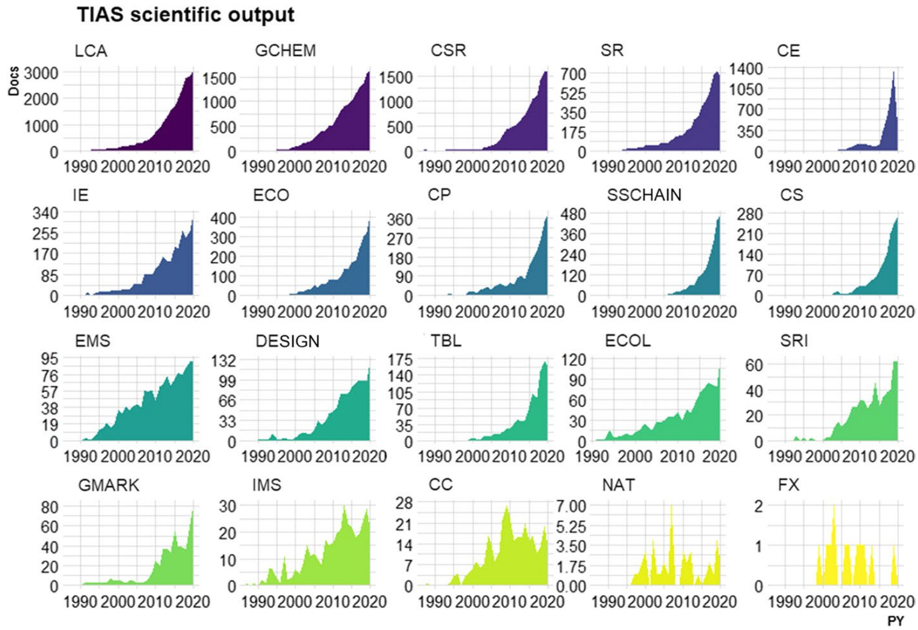

Fig. 2 Scientific evolution of the TIAs during the period of study (1987–2020)

analysed, 280 different bursting keywords, according to CiteSpace software burst analysis, have been identified. From this, we can trace the development of research hotspots. Each keyword was associated with its strength which indicates the relevance of a topic, i.e. it usually indicates potentially interesting studies that have had significant attention in a short period of time. The blue bars (time span) indicate the periods that cover the burst analysis and the red section the years when the strongest bursts occurred. According to the data, the TIAs that had the strongest citation burst were: GCHEM (585.71); IE (174.5); CE (180.89); and, ECO (62.63). TIAs, such as EMS, IE, and LCA, have had more attention based on the number of citations since the early 1990s, whereas some other TIAs (e.g. CE and SSCHAIN) have been more predominant in the last five years. Certain terms that had the longest time span bursts (in red), denoting that their concepts have a keen interest during a longer period such as IE (1995–2012) and EMS (1996–2011). Some TIAs do not present any citation burst, such as CC, NS, and FX.

4.3 Identifying interrelations between the TIAs

This section presents the TIAs interlinkages results in two levels: 1) at a higher level, the interrelations between TIAs were analysed based on a keywords co-occurrence map, whereas, 2) at a lower level, the subtopics of each one were identified based on co-citation analysis.

Table 2 Top keywords with the strongest citation burst

Keywords	Acronym	Year	Strength	Begin	End	1987 - 2020
circular economy	CE	1987	180.89	**2018**	2020	
circulareconomy	CE	1987	23.7	**2018**	2020	
cleaner production	CP	1987	56.55	**1999**	2008	
corporate social performance	CSR	1987	39.82	**1996**	2011	
corporate socialresponsibility	CSR	1987	24	**2007**	2011	
corporate social responsibility	CSR	1987	50.25	**2008**	2009	
corporate social responsibility (csr)	CSR	1987	12.68	**2009**	2011	
eco-design	DESIGN	1987	9.24	**2013**	2014	
eco-efficiency	ECO	1987	62.63	**2001**	2010	
eco-labelling	ECOL	1987	6.85	**2002**	2014	
eco-label	ECOL	1987	5.93	**2005**	2008	
environmental management	EMS	1987	39.01	**1995**	2010	
environmental management system	EMS	1987	44.42	**1996**	2011	
environmental management system	EMS	1987	44.42	**1996**	2011	
green chemistry	GCHEM	1987	585.71	**1999**	2013	
greenchemistry	GCHEM	1987	73.61	**2003**	2014	
green marketing	GMARK	1987	3.53	**2001**	2009	
industrial ecology	IE	1987	174.5	**1995**	2012	
life cycle analysis	LCA	1987	54.24	**1995**	2013	
life-cycle analysis	LCA	1987	15.81	**1995**	2012	
lca	LCA	1987	41.68	**1997**	2005	
life-cycle assessment	LCA	1987	34.33	**1997**	2011	
life cycle assessment (lca)	LCA	1987	43.41	**2000**	2010	
life cycleassessment	LCA	1987	6.97	**2000**	2002	
life cycle assessment	LCA	1987	10.48	**2002**	2003	
iso 14001	SR	1987	32.55	**2006**	2014	
integrated reporting	SR	1987	26.47	**2018**	2020	
sustainable supply chain management	SSCHAIN	1987	13.47	**2017**	2020	

Keywords were grouped with terms that were related within each TIA (e.g. 'iso 14001' and 'integrated reporting' refers to SR) and punctuation marks (e.g. 'life cycle' and 'life-cycle')

4.3.1 Keywords co-occurrence map

The topics addressed in TIAs' research were illustrated in the keyword co-occurrence map of Fig. 3. 115,251 keywords were identified during the period. Considering a minimum number of 100 occurrences of a keyword, 660 keywords meet the threshold. The highest-ranking keywords were: LCA (frequency of 16,995); GCHEM (7221); and 'Sustainability' (5117).

The information on each cluster is presented in Table 3, which shows information such as the cluster number, label assigned, number of nodes, link strength, weight, year and the top-5 most frequent keywords. The largest cluster is #1 GCHEM (with 202 nodes), closely followed by #2 LCA which also presents the higher number of links per paper (link strength_{avg} of 2596.95), denoting a stronger connection between the articles of this cluster. Cluster 3 is the one that encompasses the great majority of TIAs (CE, CP, CS, CSR, ECOL, DESIGN, EMS, GMARK, SRI, SC, SSCHAIN, and TBL). Cluster 4 is comprised

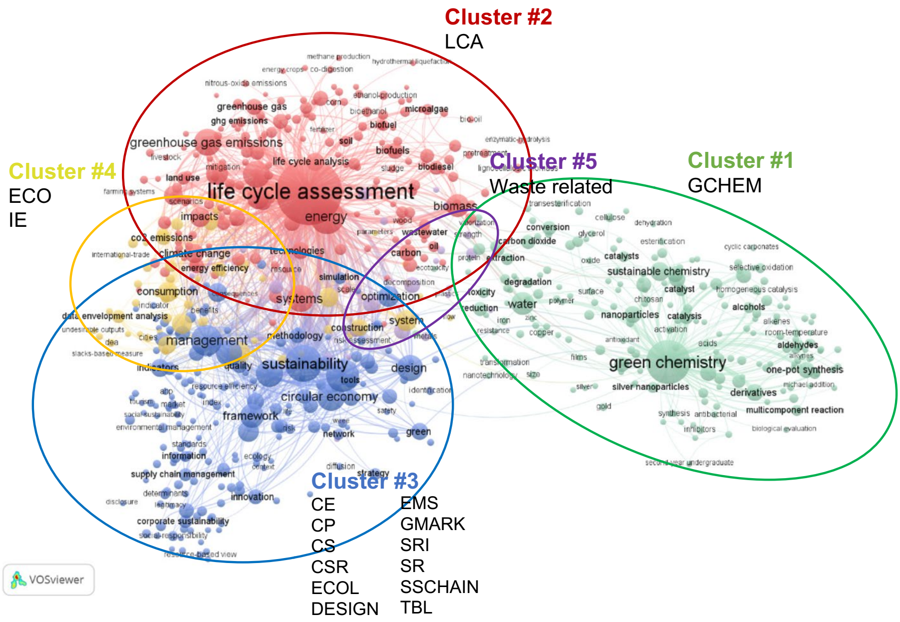

Fig. 3 Co-occurrence keywords for the TIAS (nodes = keywords; node size = proportional to publications on each node; edges = co-occurrence of keywords) (< 100 keywords). No links were found for IMS, CC, NS and FX

of two TIAs: ECO and IE, which shows that both are interrelated. The map shows that in academic research, TIAs are interrelated, with the exception of clusters 1 and 2. The biggest nodes of cluster 5 'waste-related issues' (i.e. 'waste' and 'recycling'), which does not include any TIA, were bridges between Cluster #2 and #3. These formers were the most recent (year$_{avg}$ 2016), indicating a current interest in including the recovery perspective (Table 3).

This result shows that some TIAs were more integrative and interrelated in their implementation in academic research (e.g. CSR, SR). Some TIAs present a compartmentalized approach, e.g. GCHEM and LCA. They constitute a unique cluster by themselves, denoting its relevance. LCA is interconnected with other TIAs, whereas GCHEM does not present any.

Figure 4 presents an analysis of Cluster #3 (Fig. 3), in order to provide more insights into this pool of TIAs. Cluster #1 encompasses TIAs such as CE, DESIGN, and CP. Cluster #2 includes GMARK and ECOL; Cluster #3 groups TBL and SSCHAIN and Cluster #4 integrates tools related to management and reporting (CS, CSR, SRI, SR and EMS).

4.3.2 Subtopic specialties

Figure 5 shows a circular bar plot with the top-5 research specialties for each TIA (see Table S.2.). The cluster labels were obtained from the abstract in the citing papers using the LLR algorithm. In case there is the same name for different clusters, other labels (by using LSI approach) are used, i.e. natural step has two clusters with the label 'informing LEED's'; one was changed to the label obtained by the LSI ('new trend'). The size

Table 3 Summary table with cluster information

Cluster	Label	#nodes	#link strength$_{avg}$	#weight Occurrences	#year$_{avg}$	Top-5 Most-frequent keywords and frequency (in brackets)
#1	Green chemistry	202	1289.07	278.26	2014.77	Green chemistry (7221), water (1803), sustainable chemistry (1180), nanoparticle (988), derivatives (971)
#2	Life cycle assessment	191	2596.95	452.62	2015.88	Life cycle assessment (16,995), energy (4118), systems (2667), emissions (2622), greenhouse (2497)
#3	Sustainability-related	183	2242.97	409.38	2015.65	Sustainability (5117), performance (3829), management (3479), circular economy (2739), model (2588)
#4	Industrial ecology and eco-efficiency	57	2135.25	384.72	2016.14	Industrial ecology (1540), system (1509), consumption (1453), china (1404), efficiency (1177)
#5	Waste-related issues	27	1603.96	314.81	2016.53	Waste (1129), recycling (889), recovery (825), waste management (691), concrete (484)

Labels were assigned based on the keywords within its cluster

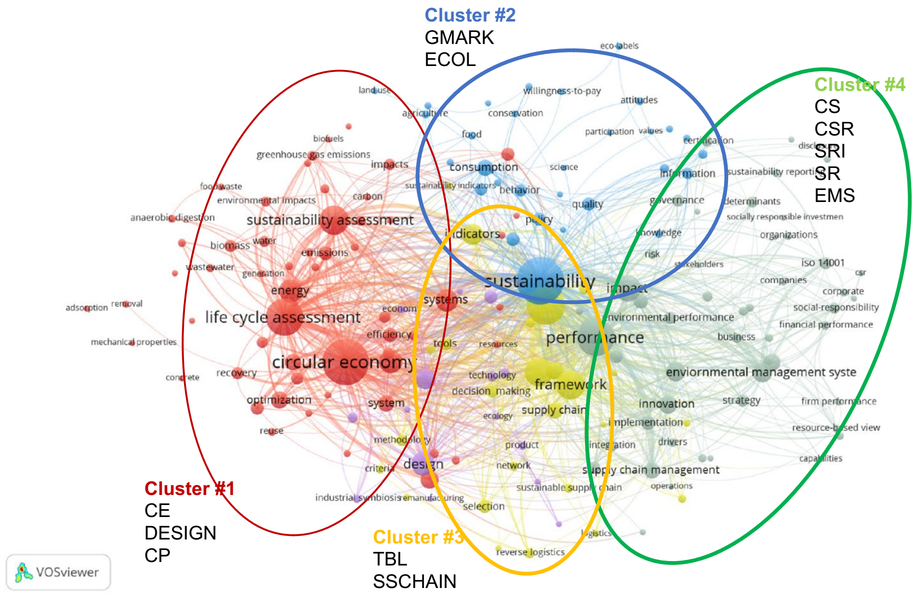

Fig. 4 Co-occurrence keywords for the TIAS of sustainability-related cluster (< 100 keywords)

of the bars indicates the number of documents that integrate each of the topics. Some TIAs shared subtopics, for example, CSR has a subtopic, TBL; TBL has one subtopic related to SSCHAIN. This shows that some tools can be complementary and can be used for strategic sustainability implementation.

The connections of each TIA with other TIAs were analysed by using a chord diagram, see Fig. 6. Each TIA constitutes a section of the circular layout. The numbers indicate the number of connections between the subtopics (i.e. a number one means this specific TIA only had one connection to another TIA). The arcs were drawn between the tools in case there are one (or more) subtopics interrelated. The size of the arc was proportional to the importance of the flow (i.e. number of subtopics that were shared). Only TIAs that present, at least, one connection were drawn. CE and LCA (7 connections each), SSCHAIN and DESIGN (6) present a higher number of links with the other TIAs. From the analysis, two profiles can be deduced: 1) 'Provider', including DESIGN (with 6 subtopics); SR (5 subtopics); and TBL (3 subtopics); 2) 'Receiver', such SSCHAIN (5), and CE (6). The latter is related to the fact that some TIAs are more 'transversal', or easily adaptable because of their integration with others (e.g. an initiative such as TBL could be better aligned with other tools).

5 Discussion

The results show publications for most TIAs (fourteen) for more than twenty years, which evidences their rate of implementation (in line with GCHEM that is established as a discipline (see Dichiarante et al., 2010)). The burst analysis indicates that some TIAs (e.g. IE, GCHEM and CE) have become 'hot topics' and have a better implementation and policy potential (see European Commission, 2020; Thomas et al., 2003).

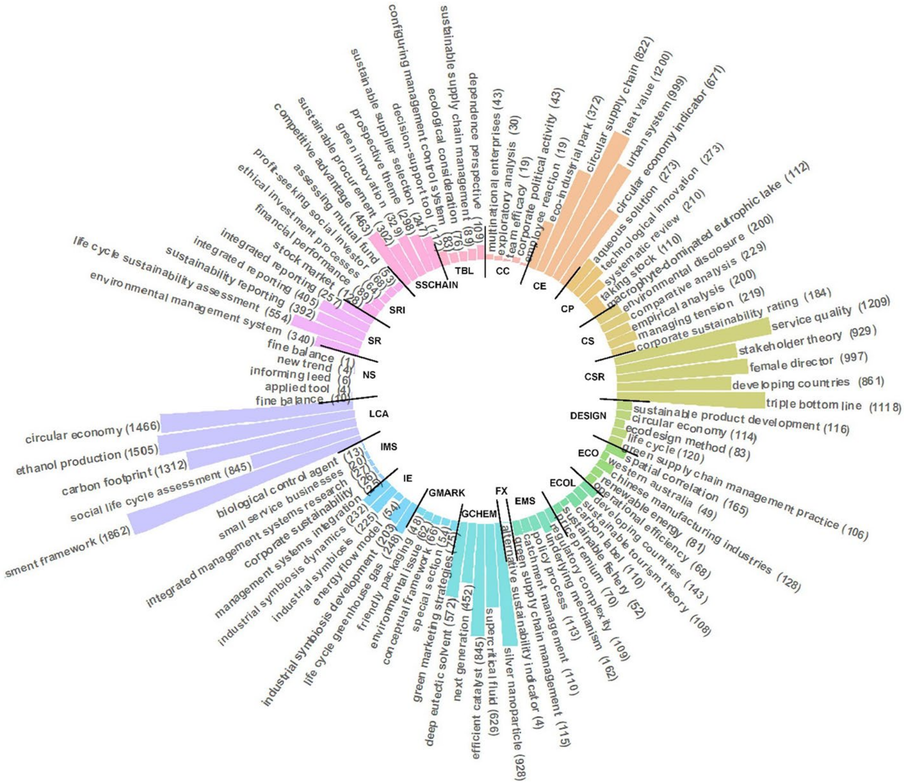

Fig. 5 Circular bar plot of the top 5 sub-topics by the twenty TIAs

The keyword co-occurrence maps show that the majority of the TIAs (and their sub-topics): (1) have a better balance, in regards to the sustainability dimension, in implementation than in 'theory' (i.e. TIAs' definitions) (complementing Chofreh & Goni, 2017); and, (2) are interrelated in academic research (providing new insights to Corsi & Arru, 2020; Glavič & Lukman, 2007; Hoogmartens et al., 2014; Lozano, 2020; Ness et al., 2007; Robèrt, 2000; Robèrt et al., 2002). The most interconnected TIAs belong to the management and reporting cluster (concurring with Lozano, 2020), whereas the least connected one is GCHEM (in contrast to Lozano, 2020).

From the interrelation analyses two types of interlinking profiles were deduced (providing new insights to Glavič & Lukman, 2007; Lozano, 2020): (1) 'Provider' profile (e.g. DESIGN); (2); and, 'Receiver' (e.g. SSCHAIN and CE).

The results from the 'theory' (i.e. TIAs definition) were compared with their 'implementation' in academic research (Table S.3) showing that all TIAs address at least one sustainability dimension, with the environmental dimension being the most frequently addressed in academic research (45%) (concurring with Atkinson et al., 2000; Lozano, 2020; Lozano & Huisingh, 2011). The TIAs focusing on social dimension are higher in academic research (22%) than in companies (contrary to Lozano, 2020 in which this dimension was not sufficiently addressed).

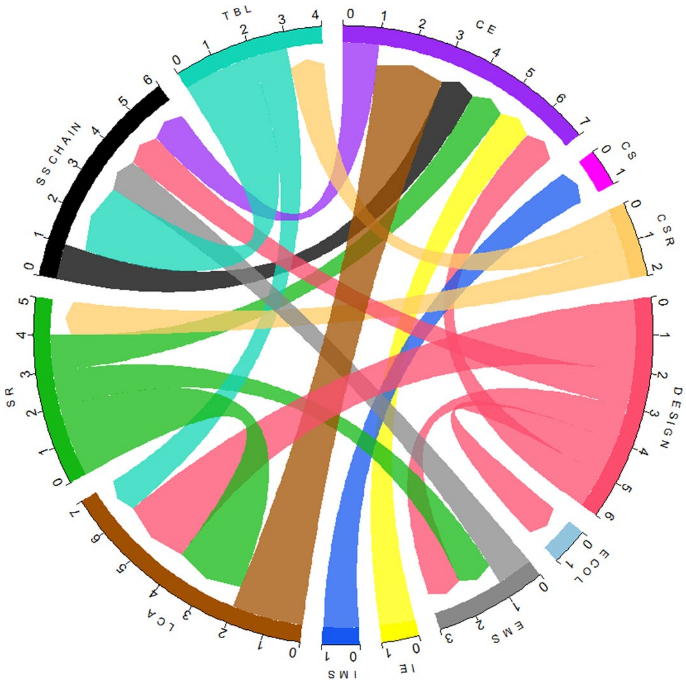

Fig. 6 Chord Diagram with the interrelations between the TIAs

The results show that some TIAs in their implementation have a more integrated approach by covering more dimensions than in 'theory' (e.g. CE, DESIGN, ECO, ECOL, EMS, GMARK, IE and LCA) and that the TIAs related to management and reporting (Fig. 3, Cluster 3) are the most interconnected and address the most sustainability dimensions (except for SR and SSCHAIN) (providing new insights into the corporate context discussed by Glavič & Lukman, 2007; Lozano, 2020).

The results were integrated to develop the 'Sustainability Implementation Framework' aimed at helping to understand the implementation of TIAs in academic research (Fig. 7). The framework compares the 'theory' (i.e. definitions), left side of the figure, with the 'implementation' (i.e. use) in academic research, right side of the figure. The TIAs were divided into three different levels (a multi-layered implementation, concurring with Ahmed & Sundaram, 2012) from general to particular (i.e. Initiatives, Approaches and Tools, based on Glavič & Lukman's, 2007 framework and complementing it with the proposals by Lozano, 2012a, 2012b, 2020). The Tools (more particular focus), the Approaches, and the Initiatives (more general focus) should be aligned for a better contribution to sustainability, and the theory and implementation should be more congruent. The triangles aim to illustrate that the sustainability dimensions are more clearly separated, whereas the circles depict the more connected.

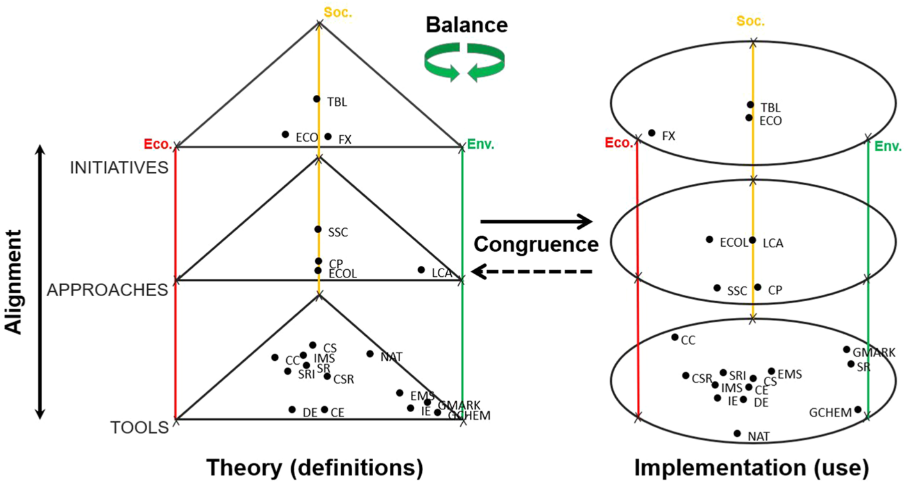

Fig. 7 Sustainability Implementation Framework (SIF) for academic research. For the theory (left figure), triangles were used to show the dimensions of sustainability more clearly separated, while for the 'implementation' circles (right figure) were used to show a stronger connection between the dimensions

6 Conclusions

In the last five decades, there has been an increasing interest in the use of tools, initiatives, and approaches (TIAs) in academic research. Sustainability plays a pivotal role in addressing their implementation and has to encompass a holistic perspective, including the four dimensions (economic, environmental, social, and time), as well as their interrelations. However, the majority of such efforts in academic research have focused on descriptive approaches (e.g. bibliometric approaches) with a limited number of tools. In addition, most of the implementation frameworks developed to date for those tools remain theoretical and none of them have been applied in the academic research.

A bibliometric analysis was conducted to analyse the implementation of the most widely used TIAs in academic research. The top twenty TIAs were analysed, covering the period 1961–2020, and bibliometric indicators such as research patterns (yearly trend), hot topics (burst analysis) as well as their interrelations (co-occurrence maps and co-citation cluster) were examined.

This study analyses the implementation of TIAs in academic research and compared against the TIAs 'theory'. The results show TIAS implementation in academic research can foster sustainability. The interrelationships between the TIAs (and their subtopics) in their implementation highlight that their use is more holistic and can better address the complexity of sustainability.

The results were integrated into a Sustainability Implementation Framework (SIF), which is aimed at helping to understand the implementation of tools in academic research. SIF demonstrates that TIAs have a more holistic and balanced approach in their implementation rather than in 'theory'. SIF shows that TIAs can improve their congruence by better linking the implementation of TIAs with their theory, which is paramount for sustainability change. SIF can be helpful to sustainability researchers for organising the information (e.g. by levels) of the implementation of the tools and can provide guidance on the different interactions in academic research, thus helping to advance the sustainability transformation.

For a better implementation of TIAs in academic research, it is necessary to address sustainability dimensions (economic, environmental, social, and time) in a holistic and balanced way, considering the alignment of general and specific efforts, i.e. TIAs, and congruence (linking 'theory' and 'implementation'). The TIAs' implementation should follow more strictly the definitions, or, perhaps, the TIAs' definitions should be redefined to encompass the insights from their implementation.

Further research should be carried out on specific case studies, countries and sectors to test the framework, which can help to gain an insight into the practical implementation of the tools. The practical use of TIAs by different types of organisations should also be explored, as well as their motivation (e.g. reason why the tools are used) and limitations. In addition, the use of these tools in innovation (e.g. research and development projects), and how to incorporate the time dimension, should also be investigated.

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Code availability Not applicable.

Declarations

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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