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Life-cycle cost analysis (LCCA): Comparing outputs for bibliographic coupling and citation links

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ABSTRACT

The life-cycle cost analysis (LCCA) is an important tool that jointly with the environmental and social life-cycle assessment provides relevant insights into studies about sustainability. This is true in the different economic sectors and social dimensions. Nonetheless, the literature shows that there is a field to be explored about this topic through bibliometric analysis. In this framework, this research aims to analyse the different items associated with the bibliographic coupling and citation links. For that, bibliographic data for the topic "life cycle cost* analysis" were considered. From the Web of Science platform, 1642 documents were taken into account in a search carried out on March 14, 2023. The intention is to highlight the top authors, countries, documents, organisations and sources. This study intends also to compare the metrics obtained for the two links and conclude if they are alternatives. In other words, it is important to show if it is indifferent, for this topic, to choose one of these links (bibliographic coupling and citation) to analyse the metrics associated with the respective items. Or if this choice depends on the objectives designed. The main findings highlight the top authors, countries, organisations and sources related to this topic. On the other hand, the results reveal that some metrics are equal for the two links, but only for a part of the observations. In this way, for the total of the observations, despite strong correlations between some metrics, the choice of the link is not indifferent and depends on the aims of the study. This is an important finding, highlighting that the choice of the link for bibliometric analysis is a crucial step to achieve robust conclusions.

1. Introduction

There are not many studies about life-cycle cost analysis (LCCA) considering bibliometric assessments. These findings from the literature show that there is a field to be explored in these domains. Some of the studies found in the scientific literature, that highlight life-cycle cost contexts taking into account bibliometric analysis, are related to the following dimensions: electric vehicles [1], wastewater management [2], construction sector [3], unitized regenerative fuel cell [4], maritime transport [5] and road infrastructures [6].

A part of the studies carried out about the LCCA focused on the construction sector [7] and infrastructures [8]. These focuses include pavement engineering [9], management [10], construction [11] and the respective materials used [12], such as pervious concrete [13], nanomaterials [14] and recycled material [15]. The concerns with sustainability worldwide and the potential impacts of these sectors on Sustainable Development Goals (SDGs) increase the interest of the scientific community in these topics and the related frameworks. Concrete repairs [16], alternative railway support material [17] and the use of waste to produce materials [18] are

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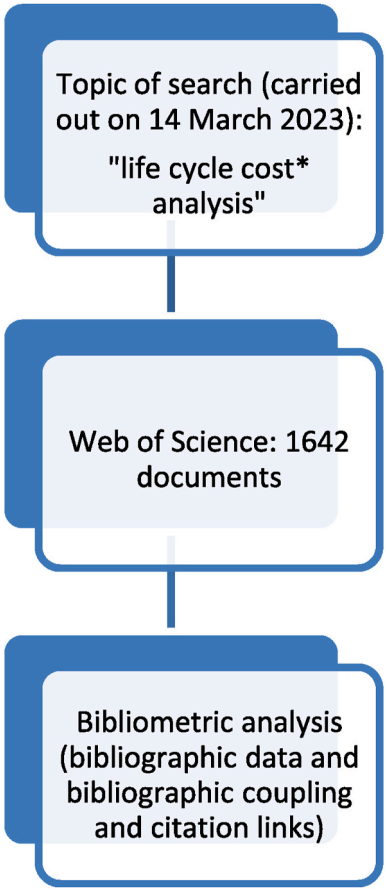

Fig. 1. Main steps considered in the methodology to achieve the objectives proposed.

included in these subjects associated with the construction and infrastructure sectors.

Buildings contribute significantly to carbon emissions and energy consumption [19] and this is a concern for several stakeholders. In these contexts, alternative approaches are needed to improve energy efficiency [20] worldwide [21]. Renewable energies [22] are examples of alternatives to promote more sustainable development. This includes photovoltaic systems [23] and biodiesel [24], for instance. The fuel cells are also eco-friendly systems to generate energy [25]. Building energy use is, in some circumstances, greater than industry and transportation consumption [26]. For example, buildings utilise around 90 % of the electricity consumed in the United Arab Emirates [27]. Buildings and infrastructures may contribute to climate change, but they are also impacted by global warming [28].

The design phase of a product or project is crucial to reduce the life cycle costs [29], playing a fundamental role in more sustainable development. This is particularly important in the construction sector to mitigate energy consumption [30]. In the context of energy use, costs, security and environmental impacts are dimensions to be considered in the respective assessments [31]. The new technologies and smart approaches may bring relevant contributions to these assessments [32].

The life cycle cost assessment in the agri-food sectors is also highlighted in the literature, because the current contexts require more resilient and sustainable agriculture and food activities [33]. Wastewater treatment is another topic where the LCCA has been taken into account by the scientific community [34]. The LCCA was also considered in studies associated with the following issues: application of biochar in rice paddy fields [35]; constructed wetlands [36]; urban agriculture [37]; best management practices [38]; and energy storage systems [39].

This literature survey reveals that more assessments are needed, on the dimensions of LCCA, to highlight trends, networks and unexplored subjects, considering broader approaches and comparing results for different links in bibliometric analyses. Choosing links that fit the proposed objectives is a fundamental step and it is important to emphasise this in the scientific literature. In these contexts, the objectives of this research are to provide more insights on the subject of LCCA and to highlight metrics related to bibliographic coupling and citation links and to compare these variables to conclude about their complementarity or If they are alternative. The novelty of this research is to analyse deeper the LCCA topic through bibliometric analysis and to compare, for this subject, the results obtained from different bibliometric links.

After this introduction section, this study has more five sections for material and methods, data analysis, results and last sections for discussion and conclusions.

Table 1
Top 30 items with the highest number of documents for bibliographic coupling links.

Authors	Cluster	Links	Total link strength	Documents
Hong, Taehoon	28	624	6005	17
Koo, Choongwan	28	330	5285	13
Santos, Joao	1	668	3657	10
Lagaros, Nikos D.	2	357	4698	9
Venanzi, Ilaria	2	468	5189	9
Wang, Hao	1	411	1717	9
Al-Qadi, Imad L.	1	511	1438	8
Berawi, Mohammed Ali	17	325	1536	8
Ferreira, Adelino	1	646	2962	8
Harvey, John T.	1	404	1716	8
Krarti, Moncef	5	131	421	8
Rahman, Ataur	24	202	2424	8
Tiwari, G. N.	9	229	1092	8
Gransberg, Douglas D.	1	347	1541	7
Li, Yue	2	320	1997	7
Miraj, Perdana	17	325	1433	7
Qiao, Yaning	1	661	3729	7
Swei, Omar	1	673	3582	7
Frangopol, Dan M.	2	732	2477	6
Lee, Eul-Bum	7	435	1182	6
Li, Hui	1	703	2340	6
Li, Zongzhi	1	250	1721	6
Stewart, Mg	2	182	914	6
Zhang, Qiong	8	356	2282	6
Aizpuru, Iosu	11	16	1002	5
Asadi, Payam	2	397	1766	5
Daouas, Naouel	3	314	3230	5
Estekanchi, H. E.	2	193	2000	5
Frangopol, Dm	2	253	797	5
Gregory, Jeremy	1	495	2694	5

2. Material and methods

To achieve the objectives proposed, this study considered 1642 documents obtained from the Web of Science Core Collection [40] for the topic "life cycle cost* analysis". This search was carried out on March 14, 2023. This information was analysed through bibliometric analysis, considering bibliographic data. Bibliographic coupling and citation links were taken into account, as well as authors, countries, documents, organisations and sources items. It was used a full counting network, with 0 as the minimum number of citation of a document (for document items) and 1 as the minimum number of documents of an author, country, organisation and source (for all items except documents). The 1642 documents were found in the Web of Science database without any restriction for period, type of documents, or other filter.

It could be considered also other databases to obtain documents for the bibliometric analysis, nonetheless, the number of documents identified in the Web of Science seems enough to achieve the objectives proposed. In any case, the results here identified may be compared with the findings of future research that consider insights from other databases (Scopus, for example).

To compare the metrics of the two links considered (bibliographic coupling and citation), summary statistics and Spearman's rank correlation matrices [41] were obtained, following Stata software [42–44] procedures. For the bibliometric analysis, the VOSviewer [45–47] procedures were followed. The VOSviewer software has been used worldwide by several authors and is adjusted for the approaches carried out to achieve the aims designed for this research.

Bibliometric analysis is an important approach that has been considered worldwide by different researchers to address assessments associated with diverse subjects and dimensions [48–51].

The several steps followed in this research took account of the PRISMA statement [52] and have been summarised in Fig. 1.

3. Data analysis

In this section, it will be considered a subsection for each one of the following items: authors; countries; organisations; and sources. In each one of these items will be assessed the results for the bibliographic coupling and citation links through the following metrics: cluster; links (number of links between the items); total link strength (total strength of the links among items); and documents (number of documents).

3.1. Authors as items

The top 10 authors with more documents for the bibliographic coupling links are the following (Table 1): Hong, Taehoon; Koo, Choongwan; Santos, Joao; Lagaros, Nikos D.; Venanzi, Ilaria; Wang, Hao; Al-Qadi, Imad L.; Berawi, Mohammed Ali; Ferreira, Adelino;

Table 2
Top 30 items with the highest number of documents for citation links.

Authors	Cluster	Links	Total link strength	Documents
Hong, Taehoon	12	54	161	17
Koo, Choongwan	12	38	139	13
Santos, Joao	19	129	196	10
Lagaros, Nikos D.	2	81	184	9
Venanzi, Ilaria	2	81	279	9
Wang, Hao	30	88	116	9
Al-Qadi, Imad L.	19	33	37	8
Berawi, Mohammed Ali	37	23	25	8
Ferreira, Adelino	19	121	168	8
Harvey, John T.	3	70	94	8
Krarti, Moncef	37	11	19	8
Rahman, Ataur	17	58	100	8
Tiwari, G. N.	12	44	63	8
Gransberg, Douglas D.	3	61	93	7
Li, Yue	40	22	39	7
Miraj, Perdana	37	23	25	7
Qiao, Yaning	13	101	161	7
Swei, Omar	11	112	172	7
Frangopol, Dan M.	23	16	27	6
Lee, Eul-Bum	29	74	94	6
Li, Hui	24	40	41	6
Li, Zongzhi	28	65	101	6
Stewart, Mg	18	73	82	6
Zhang, Qiong	20	23	24	6
Aizpuru, Iosu	4	20	45	5
Asadi, Payam	2	18	29	5
Daouas, Naouel	1	131	225	5
Estekanchi, H. E.	2	32	85	5
Frangopol, Dm	23	13	16	5
Gregory, Jeremy	11	107	181	5

Table 3
Top 30 items with the highest number of documents for bibliographic coupling links.

Countries	Cluster	Links	Total link strength	Documents
Usa	11	80	21,044	441
Peoples R China	2	84	16,296	193
South Korea	11	73	4380	94
Turkey	2	72	6566	79
India	7	70	3206	78
Australia	3	79	7931	77
Italy	5	78	6616	75
England	12	79	7043	68
Canada	3	76	4264	64
Malaysia	3	79	6112	52
Iran	5	77	5180	51
Spain	1	77	4292	48
Sweden	1	68	2587	45
Germany	8	71	3102	38
Japan	6	59	1829	33
Portugal	4	67	1807	29
Greece	5	67	2516	27
Indonesia	6	65	1672	27
France	1	65	2132	25
Singapore	9	67	1757	21
Egypt	3	50	1381	19
Saudi Arabia	3	59	2679	19
Switzerland	1	52	1257	19
Pakistan	8	69	2853	18
Netherlands	8	62	1801	17
Belgium	7	73	2816	16
Norway	6	59	626	14
Poland	3	54	464	14
Austria	1	42	449	13
Brazil	1	56	812	13

Table 4
Top 30 items with the highest number of documents for citation links.

Countries	Cluster	Links	Total link strength	Documents
Usa	4	60	814	441
Peoples R China	6	52	482	193
South Korea	6	39	150	94
Turkey	7	41	265	79
India	2	35	97	78
Australia	2	53	226	77
Italy	5	46	253	75
England	4	41	164	68
Canada	3	46	205	64
Malaysia	9	48	253	52
Iran	5	34	161	51
Spain	10	40	109	48
Sweden	3	35	113	45
Germany	4	29	86	38
Japan	7	24	63	33
Portugal	8	33	86	29
Greece	5	25	91	27
Indonesia	9	13	33	27
France	8	21	57	25
Singapore	6	26	78	21
Egypt	10	10	26	19
Saudi Arabia	8	18	45	19
Switzerland	1	12	25	19
Pakistan	4	29	79	18
Netherlands	6	21	47	17
Belgium	1	27	92	16
Norway	3	10	17	14
Poland	1	18	23	14
Austria	1	10	10	13
Brazil	2	18	20	13

Table 5
Top 30 items with the highest number of documents for bibliographic coupling links.

Organisations	Cluster	Links	Total link strength	Documents
Hong Kong Polytech Univ	1	583	3505	24
Univ Colorado	2	382	2067	22
Iowa State Univ	15	348	2960	19
Yonsei Univ	26	369	2492	19
Tongji Univ	25	557	3824	18
Indian Inst Technol	2	330	1672	16
Southeast Univ	1	428	2815	16
Univ Calif Davis	1	344	1599	15
Univ Teknol Petronas	1	517	3689	14
Nanyang Technol Univ	14	257	1496	12
Chalmers Univ Technol	13	300	1438	11
Delft Univ Technol	28	328	1668	11
Georgia Inst Technol	35	234	993	11
Purdue Univ	26	259	1312	11
Rutgers State Univ	1	302	1207	11
Sharif Univ Technol	2	272	1986	11
Swiss Fed Inst Technol	13	298	1657	11
Texas A&M Univ	1	278	1519	11
Univ Calif Berkeley	15	306	1165	11
Univ Coimbra	1	410	1915	11
Univ Newcastle	2	180	1207	11
Univ Nottingham	1	444	2420	11
China Univ Min & Technol	34	448	2763	10
Chinese Acad Sci	18	199	1935	10
Natl Tech Univ Athens	2	180	1928	10
Univ Illinois	1	303	1001	10
Univ Indonesia	1	206	457	10
Univ Perugia	2	206	2443	10
Univ Waterloo	15	163	533	10
Virginia Polytech Inst & State Univ	1	336	1873	10

Table 6
Top 30 items with the highest number of documents for citation links.

Organisations	Cluster	Links	Total link strength	Documents
Hong Kong Polytech Univ	23	57	78	24
Univ Colorado	29	19	28	22
Iowa State Univ	30	79	139	19
Yonsei Univ	23	51	86	19
Tongji Univ	37	69	101	18
Indian Inst Technol	10	48	60	16
Southeast Univ	19	65	88	16
Univ Calif Davis	20	65	90	15
Univ Teknol Petronas	38	130	180	14
Nanyang Technol Univ	17	44	61	12
Chalmers Univ Technol	9	11	23	11
Delft Univ Technol	19	39	40	11
Georgia Inst Technol	6	7	8	11
Purdue Univ	16	30	46	11
Rutgers State Univ	4	79	109	11
Sharif Univ Technol	18	27	59	11
Swiss Fed Inst Technol	9	21	36	11
Texas A&M Univ	22	37	53	11
Univ Calif Berkeley	17	45	55	11
Univ Coimbra	40	71	101	11
Univ Newcastle	21	41	54	11
Univ Nottingham	2	62	91	11
China Univ Min & Technol	2	64	90	10
Chinese Acad Sci	3	16	21	10
Natl Tech Univ Athens	18	38	83	10
Univ Illinois	16	24	27	10
Univ Indonesia	29	4	4	10
Univ Perugia	21	44	125	10
Univ Waterloo	19	36	42	10
Virginia Polytech Inst & State Univ	40	53	76	10

Table 7
Top 30 items with the highest number of documents for bibliographic coupling links.

Sources	Cluster	Links	Total link strength	Documents
Journal of Cleaner Production	6	301	3501	63
Transportation Research Record	1	209	1644	59
Sustainability	1	307	2678	49
Applied Energy	5	183	2270	38
Energy and Buildings	5	242	2518	34
Energy	12	128	1032	31
Structure and Infrastructure Engineering	3	212	1923	28
Energies	8	176	1135	24
Renewable & Sustainable Energy Reviews	7	215	1238	16
Construction and Building Materials	1	141	516	14
International Journal of Pavement Engineering	1	126	800	14
International Journal of Life Cycle Assessment	6	167	984	13
Sustainable Cities and Society	13	137	543	13
Journal of Infrastructure Systems	1	190	956	12
Renewable Energy	2	95	276	12
Applied Thermal Engineering	5	74	1180	11
Building and Environment	9	105	380	11
Energy Conversion and Management	5	86	604	11
Journal of Building Engineering	5	182	1363	11
Journal of Transportation Engineering	1	96	650	11
Applied Sciences-Basel	9	135	441	10
Journal of Transportation Engineering Part B-Pavements	1	110	594	10
International Journal of Hydrogen Energy	7	88	182	9
Journal of Structural Engineering	3	102	512	9
Reliability Engineering & System Safety	3	106	582	9
Sustainable Energy Technologies and Assessments	15	90	753	9
Bulletin of Earthquake Engineering	3	67	766	8
Engineering Structures	3	124	909	8
Life-Cycle Analysis and Assessment in Civil Engineering: Towards an	12	113	400	8
Resources Conservation and Recycling	14	106	323	8

Table 8
Top 30 items with the highest number of documents for citation links.

Sources	Cluster	Links	Total link strength	Documents
journal of cleaner production	15	74	172	63
transportation research record	23	55	137	59
sustainability	10	57	128	49
applied energy	20	69	203	38
energy and buildings	25	57	144	34
energy	24	38	75	31
structure and infrastructure engineering	26	46	78	28
energies	5	25	48	24
renewable & sustainable energy reviews	4	48	94	16
construction and building materials	32	24	36	14
international journal of pavement engineering	8	32	61	14
international journal of life cycle assessment	19	26	44	13
sustainable cities and society	16	26	42	13
journal of infrastructure systems	35	31	50	12
renewable energy	34	16	22	12
applied thermal engineering	13	41	132	11
building and environment	29	19	28	11
energy conversion and management	17	19	35	11
journal of building engineering	28	40	77	11
journal of transportation engineering	8	31	60	11
applied sciences-basel	8	13	18	10
journal of transportation engineering part b-pavements	2	12	22	10
international journal of hydrogen energy	12	9	15	9
journal of structural engineering	18	9	11	9
reliability engineering & system safety	1	31	48	9
sustainable energy technologies and assessments	21	20	36	9
bulletin of earthquake engineering	1	14	34	8
engineering structures	1	11	22	8
life-cycle analysis and assessment in civil engineering: towards an	9	4	5	8
resources conservation and recycling	11	12	17	8

and Harvey, John T. The same top 10 (and top 30) authors were found for citation links (Table 2) with the same number of documents, however with a different network. This is visible when analysing the results for the cluster, links and total link strength metrics. In any case, some of the authors with the highest number of documents have also the highest total link strength, for example.

3.2. Countries of affiliation as items

USA, Peoples R China, South Korea, Turkey, India, Australia, Italy, England, Canada, Malaysia, Iran, Spain, Sweden, Germany, Japan, Portugal and Greece are the countries with the highest number of documents (Table 3) for bibliographic coupling links. For the citation links the top 30 countries of affiliation are the same and, again, with the same number of documents (Table 4). The results for the cluster, links and total link strength metrics reveal that the network between the different countries associated with the bibliographic coupling links is distinct from that found for citation links.

3.3. Organisations of affiliation as items

Table 5 show that the top 10 organisations with the biggest number of documents for bibliographic coupling links are the following: Hong Kong Polytech Univ; Univ Colorado; Iowa State Univ; Yonsei Univ; Tongji Univ; Indian Inst Technol; Southeast Univ; Univ Calif Davis; Univ Teknol Petronas; and Nanyang Technol Univ. The same top 10 (top 30) organisations were identified for the citation links (Table 6). The number of links and total link strength is higher for the bibliographic coupling links than for the citation ones.

3.4. Sources as items

The top 30 sources with the greatest number of documents for bibliographic coupling links are related to cleaner production, transportation, sustainability, energy, buildings, infrastructures, construction, pavement, life cycle assessment, cities and society, thermal engineering, applied sciences, reliability engineering, structures and recycling (Table 7). The results for the top 30 sources and the number of documents in these sources are the same for the two links (bibliographic coupling and citation, nonetheless with different networks, such as revealing the cluster, links and total link strength metrics). The results for the citation links are those presented in Table 8.

4. Results

Each one of the following subsections is associated with the authors, countries, documents, organisations and sources items. In each

Table 9
Matched observations from merged information associated with bibliographic coupling and citation links.

Result	Observations
not matched	1650
from master	1586 (_merge = = 1)
from using	64 (_merge = = 2)
matched	2245 (_merge = = 3)

Table 10
Summary statistics from merged information associated with bibliographic coupling and citation links.

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Cluster (BC)	3895	11	13	1	76
Links (BC)	3895	108	116	1	1006
Total link strength (BC)	3895	374	468	2	6005
Documents (BC)	3895	1	1	1	17
Citations (BC)	3895	21	50	0	946
Normalised citations (BC)	3895	1	2	0	34
Average publication year (BC)	3857	2017	5	1982	2023
Average citations (BC)	3895	16	37	0	713
Average normalised citations (BC)	3857	1	2	0	28
Cluster (C)	2245	15	11	1	45
Links (C)	2245	15	18	1	229
Total link strength (C)	2245	18	25	1	279
Documents (C)	2245	1	1	1	17
Citations (C)	2245	28	62	0	946
Normalised citations (C)	2245	2	3	0	34
Average publication year (C)	2217	2017	5	1998	2023
Average citations (C)	2245	21	45	0	713
Average normalised citations (C)	2217	1	2	0	28

Note: (BC), bibliographic coupling links; (C), citation links.

subsection, the observations obtained for bibliographic coupling links were merged with those found for citation links. Summary statistics are presented, as well as Spearman's rank correlation coefficients, for the merged information.

4.1. Authors as items

Table 9 reveals that from the merged information related to the two links (bibliographic coupling and citation), 2245 observations matched and 1650 not matched. The information related to the bibliographic coupling links has more observations (maximum of 3895) than that associated with citation links (maximum of 2309). On average, for the bibliographic coupling links were obtained 11 clusters (maximum 76), 108 links (maximum 1006), 374 total link strength (maximum 6005), 1 document (maximum 17), 21 citation (maximum 946), 1 normalised citation (maximum 34), 2017 as the average publication year (maximum 2023), 16 average citations (maximum 713) and 1 average normalised citations in a maximum of 28 (Table 10). For the citation links the results of the summary statistics are similar, however with lower values for the maximum in the clusters, links and total link strength. The normalised citations correct for the effect of the time in the number of citations (older documents may have more citations). Despite, the similarities between the information for the two links highlighted before, the strongest correlations were found among the links and the total link strength metrics inside each link (bibliographic coupling and citation), such as presented in Table 11. There are also strong correlations among the documents and between the citations of the two links.

4.2. Countries as items

Only 8 observations not matched between the information of the two links merged in a total of 88 observations (Table 12). The summary statistics of the several metrics are similar for the two links (with the exception of the cluster, links and total link strength findings), specifically in the results for the maximum (Table 13). In addition, there are strong correlations between the links, total link strength, documents and citations inside each link (bibliographic coupling and citation), such showed in Table 14, and between the two links.

4.3. Documents as items

From the information related to the two links merged, 788 observations matched in a total of 1390 observations (Table 15). Table 16 reveals, as verified in the previous section, that the summary statistics are similar for the metrics of the two links, with the exception of the metrics related to the organisation (cluster, links and total link strength) of the network. The bibliographic coupling

Table 11
Spearman's rank correlation for merged information associated with bibliographic coupling and citation links.

	Cluster (BC)	Links (BC)	Total link strength (BC)	Documents (BC)	Citations (BC)	Cluster (C)	Links (C)	Total link strength (C)	Documents (C)	Citations (C)
Cluster (BC)	1.000									
Links (BC)	−0.4280*	1.000								
	(0.000)									
Total link strength (BC)	−0.2174*	0.8139*	1.000							
	(0.000)	(0.000)								
Documents (BC)	−0.0472*	0.3176*	0.4380*	1.000						
	(0.025)	(0.000)	(0.000)							
Citations (BC)	0.0731*	0.1027*	0.1806*	0.3253*	1.000					
	(0.001)	(0.000)	(0.000)	(0.000)						
Cluster (C)	0.1831*	−0.1132*	−0.1200*	0.014	−0.022	1.000				
	(0.000)	(0.000)	(0.000)	(0.515)	(0.299)					
Links (C)	−0.1820*	0.4707*	0.5143*	0.3630*	0.4089*	−0.1828*	1.000			
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)				
Total link strength (C)	−0.1764*	0.4584*	0.5264*	0.4191*	0.4224*	−0.1820*	0.9863*	1.000		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)			
Documents (C)	−0.0472*	0.3176*	0.4380*	1.0000*	0.3253*	0.014	0.3630*	0.4191*	1.000	
	(0.025)	(0.000)	(0.000)	(0.000)	(0.000)	(0.515)	(0.000)	(0.000)		
Citations (C)	0.0731*	0.1027*	0.1806*	0.3253*	1.0000*	−0.022	0.4089*	0.4224*	0.3253*	1.000
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.299)	(0.000)	(0.000)	(0.000)	

Note: (BC), bibliographic coupling links; (C), citation links. *, Statistically significant at 5%.

Table 12
Matched observations from merged information associated with bibliographic coupling and citation links.

Result	Observations
not matched	8
from master	8 (_merge = = 1)
from using	0 (_merge = = 2)
matched	80 (_merge = = 3)

Table 13
Summary statistics from merged information associated with bibliographic coupling and citation links.

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Cluster (BC)	88	5	3	1	12
Links (BC)	88	46	22	1	84
Total link strength (BC)	88	1732	3161	1	21,044
Documents (BC)	88	23	53	1	441
Citations (BC)	88	383	766	0	5702
Normalised citations (BC)	88	25	49	0	345
Average publication year (BC)	88	2017	3	2007	2022
Average citations (BC)	88	18	28	0	238
Average normalised citations (BC)	88	1	1	0	9
Cluster (C)	80	5	3	1	12
Links (C)	80	17	15	1	60
Total link strength (C)	80	64	116	1	814
Documents (C)	80	25	55	1	441
Citations (C)	80	420	794	0	5702
Normalised citations (C)	80	27	51	0	345
Average publication year (C)	80	2017	2	2009	2021
Average citations (C)	80	20	29	0	238
Average normalised citations (C)	80	1	1	0	9

Note: (BC), bibliographic coupling links; (C), citation links.

Table 14
Spearman's rank correlation for merged information associated with bibliographic coupling and citation links.

	Cluster (BC)	Links (BC)	Total link strength (BC)	Documents (BC)	Citations (BC)	Cluster (C)	Links (C)	Total link strength (C)	Documents (C)	Citations (C)
Cluster (BC)	1.000									
Links (BC)	0.113 (0.319)	1.000								
Total link strength (BC)	0.139 (0.220)	0.9279* (0.000)	1.000							
Documents (BC)	0.082 (0.471)	0.9040* (0.000)	0.9049* (0.000)	1.000						
Citations (BC)	0.014 (0.900)	0.7958* (0.000)	0.8548* (0.000)	0.8556* (0.000)	1.000					
Cluster (C)	0.165 (0.144)	0.089 (0.433)	0.196 (0.081)	0.143 (0.207)	0.144 (0.204)	1.000				
Links (C)	0.181 (0.107)	0.9028* (0.000)	0.9201* (0.000)	0.8612* (0.000)	0.8498* (0.000)	0.110 (0.333)	1.000			
Total link strength (C)	0.196 (0.081)	0.8833* (0.000)	0.9376* (0.000)	0.8577* (0.000)	0.8549* (0.000)	0.185 (0.101)	0.9820* (0.000)	1.000		
Documents (C)	0.082 (0.471)	0.9040* (0.000)	0.9049* (0.000)	1.0000* (0.000)	0.8556* (0.000)	0.143 (0.207)	0.8612* (0.000)	0.8577* (0.000)	1.000	
Citations (C)	0.014 (0.900)	0.7958* (0.000)	0.8548* (0.000)	0.8556* (0.000)	1.0000* (0.000)	0.144 (0.204)	0.8498* (0.000)	0.8549* (0.000)	0.8556* (0.000)	1.000

Note: (BC), bibliographic coupling links; (C), citation links. *, Statistically significant at 5%.

links have more observations than the citation ones. The strongest correlations occur inside each link between the links and the total link strength and among the citations and the normalised citations (Table 17). There is also strong correlation between the citations, normalised citations and publication year of the two links.

Table 15
Matched observations from merged information associated with bibliographic coupling and citation links.

Result	Observations
not matched	602
from master	575 (_merge = = 1)
from using	27 (_merge = = 2)
matched	788 (_merge = = 3)

Table 16
Summary statistics from merged information associated with bibliographic coupling and citation links.

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Cluster (BC)	1390	5	3	1	16
Links (BC)	1390	31	32	1	278
Total link strength (BC)	1390	50	65	1	516
Citations (BC)	1390	18	44	0	940
Normalised citations (BC)	1390	1	2	0	34
Publication year (BC)	1377	2016	6	1982	2023
Cluster (C)	788	15	11	1	45
Links (C)	788	5	5	1	46
Citations (C)	788	25	55	0	940
Normalised citations (C)	788	1	2	0	34
Publication year (C)	779	2016	5	1998	2023

Note: (BC), bibliographic coupling links; (C), citation links.

4.4. Organisations as items

After merging the information from the two links (bibliographic coupling and citation) 910 observations matched in a total of 1381 (Table 18). Observing the summary statistics presented in Table 19, the results for the maximum, in both links, for the documents, citations, normalised citations, average publication year, average citations and average normalised citations metrics are, respectively, the following: 24; 1002; 41; 2023; 713; and 28. The values for the maximum in the summary statistics related to the cluster, links and total link strength metrics of the bibliographic coupling links are, respectively, 42, 583 and 3824 and of the citation links are 41, 130 and 180. Regarding the correlation between metrics, the highest values for the Spearman' rank coefficients were found inside each link among the links and the total link strength (Table 20). There is also strong correlation between the documents and among citations of the two links. There are too correlations, however weaker, between the documents and the citations, as well as among these metrics and the links and the total link strength.

4.5. Sources as items

Table 21 shows that 322 observations matched (in a total of 575) in the information merged from the bibliographic coupling and citation links. From the summary statistics for the bibliographic coupling links, the averages of the cluster, links, total link strength, citations, normalised citations, average publication year, average citations and average normalised citations are, respectively, the following: 6; 31; 115; 3; 45; 3; 2015; 10; and 1. For the citation links the average for these metrics is: 15; 6; 11; 4; 75; 5; 2016; 13; 1 (Table 22). The highest results for the Spearman's rank correlation coefficients are (Table 23), as found in previous subsections, inside each link and between the links and the total link strength, as well as among these metrics and the documents and the citations (and between these two metrics). There are also strong correlations between documents and among citations of the two links.

5. Discussion

This research aimed to present insights about the metrics associated with bibliographic coupling and citation links, considering bibliographic data. It was intended also to compare the metrics of these two links to conclude if they are alternative or complementary. For that 1642 documents were taken into account from the Web of Science in a search carried out on March 14, 2023 for the topic "life cycle cost* analysis". This information was analysed following VOSviewer (for the bibliometric analysis) and Stata (for the results obtained to compare the metrics related to the two links) procedures.

The literature review highlights the interest of the scientific community in the application of the LCCA in the construction and infrastructure sectors. Some of this literature focused on the buildings' energy consumption and pavement materials, from a perspective of identifying more sustainable practices. The design phase of products and projects is crucial to mitigate life cycle costs and impacts. In any case, the LCCA has been considered also in domains associated with the agricultural and food sectors, urban agriculture, energy systems and constructed wetlands. These findings highlight that there is a field to be explored, related to the LCCA dimensions, in some issues, such as those related to the agricultural sector. The life cycle assessments are also important in agriculture,

Table 17
Spearman's rank correlation for merged information associated with bibliographic coupling and citation links.

	Cluster (BC)	Links (BC)	Total link strength (BC)	Citations (BC)	Normalised citation (BC)	Publication year (BC)	Cluster (C)	Links (C)	Citations (C)	Normalised citations (C)	Publication Year (C)
Cluster (BC)	1.000										
Links (BC)	−0.1218*	1.000									
	(0.001)										
Total link strength	−0.035	0.9454*	1.000								
(BC)	(0.333)	(0.000)									
Citations (BC)	0.0982*	−0.020	0.017	1.000							
	(0.006)	(0.577)	(0.633)								
Normalised citation	0.0987*	0.025	0.062	0.8903*	1.000						
(BC)	(0.006)	(0.494)	(0.086)	(0.000)							
Publication year	0.026	0.1303*	0.1271*	−0.4413*	−0.1023*	1.000					
(BC)	(0.466)	(0.000)	(0.000)	(0.000)	(0.004)						
Cluster (C)	−0.1080*	−0.2650*	−0.3243*	−0.007	−0.029	−0.049	1.000				
	(0.003)	(0.000)	(0.000)	(0.837)	(0.413)	(0.172)					
Links (C)	0.005	0.4813*	0.5312*	0.3364*	0.3391*	−0.059	−0.2858*	1.000			
	(0.892)	(0.000)	(0.000)	(0.000)	(0.000)	(0.100)	(0.000)				
Citations (C)	0.0982*	−0.020	0.017	1.0000*	0.8903*	−0.4413*	−0.007	0.3364*	1.000		
	(0.006)	(0.577)	(0.633)	(0.000)	(0.000)	(0.000)	(0.837)	(0.000)			
Normalised	0.0987*	0.025	0.062	0.8903*	1.0000*	−0.1023*	−0.029	0.3391*	0.8903*	1.000	
citations (C)	(0.006)	(0.494)	(0.086)	(0.000)	(0.000)	(0.004)	(0.413)	(0.000)	(0.000)		
Publication Year	0.026	0.1303*	0.1271*	−0.4413*	−0.1023*	1.0000*	−0.049	−0.059	−0.4413*	−0.1023*	1.000
(C)	(0.466)	(0.000)	(0.000)	(0.000)	(0.004)	(0.000)	(0.172)	(0.100)	(0.000)	(0.004)	

Note: (BC), bibliographic coupling links; (C), citation links. *, Statistically significant at 5%.

Table 18
Matched observations from merged information associated with bibliographic coupling and citation links.

Result	Observations
not matched	471
from master	460 (_merge = = 1)
from using	11 (_merge = = 2)
matched	910 (_merge = = 3)

Table 19
Summary statistics from merged information associated with bibliographic coupling and citation links.

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Cluster (BC)	1381	10	9	1	42
Links (BC)	1381	68	77	1	583
Total link strength (BC)	1381	284	417	1	3824
Documents (BC)	1381	2	2	1	24
Citations (BC)	1381	32	70	0	1002
Normalised citations (BC)	1381	2	4	0	41
Average publication year (BC)	1369	2017	5	1994	2023
Average citations (BC)	1381	16	33	0	713
Average normalised citations (BC)	1369	1	2	0	28
Cluster (C)	910	15	11	1	41
Links (C)	910	10	13	1	130
Total link strength (C)	910	13	19	1	180
Documents (C)	910	2	3	1	24
Citations (C)	910	43	84	0	1002
Normalised citations (C)	910	3	4	0	41
Average publication year (C)	902	2017	5	1998	2023
Average citations (C)	910	20	39	0	713
Average normalised citations (C)	902	1	2	0	28

Note: (BC), bibliographic coupling links; (C), citation links.

but more contributions are needed to standardise methodologies and variables.

The bibliometric analysis shows that the top authors with more documents are the following: Hong, Taehoon; Koo, Choongwan; Santos, Joao; Lagaros, Nikos D.; Venanzi, Ilaria; Wang, Hao; Al-Qadi, Imad L.; Berawi, Mohammed Ali; Ferreira, Adelino; and Harvey, John T. The top countries are the USA, Peoples R China, South Korea, Turkey, India, Australia, Italy, England, Canada, Malaysia, Iran, Spain, Sweden, Germany, Japan, Portugal and Greece. The top 10 organisations with more documents are the following: Hong Kong Polytech Univ; Univ Colorado; Iowa State Univ; Yonsei Univ; Tongji Univ; Indian Inst Technol; Southeast Univ; Univ Calif Davis; Univ Teknol Petronas; and Nanyang Technol Univ. The top sources with the greatest number of documents are related with, for example, transportation, construction, infrastructures, sustainability, energy and recycling. These results show that it is possible to enlarge the networking on these topics related to the LCCA and to cover other subjects in the research carried out.

6. Conclusions

The findings obtained highlight that in terms of practical implications, there is still a field to be explored by the literature about the applications of the LCCA, because the current literature seems to be focused on cleaner production, transportation, energy, buildings, infrastructures, construction, pavement, cities and society, thermal engineering, reliability engineering, structures and recycling. Additionally, the results obtained from the benchmarking between the metrics of the two links reveal that the choice of the link (bibliographic coupling or citation) is not indifferent and must takes into account the objectives proposed. This is highlighted by the weak correlations among some metrics of the bibliographic coupling and citation links. These insights emphasise that a first and crucial step in bibliometric analysis is to choose the link(s) more adjusted to the research aims.

For policy recommendations, it is suggested to promote life cycle assessments in other domains and world realities to better achieve worldwide the Sustainable Development Goals. In future research, it could be interesting to bring more insights about the LCCA application in agriculture. This study presents the limitations of bibliometric analyses. In fact, the results are dependent on the search keywords considered. Therefore, perhaps other search keywords could be tested in future research.

Data availability statement

Data will be made available on request.

Table 20
Spearman's rank correlation for merged information associated with bibliographic coupling and citation links.

	Cluster (BC)	Links (BC)	Total link strength (BC)	Documents (BC)	Citations (BC)	Cluster (C)	Links (C)	Total link strength (C)	Documents (C)	Citations (C)
Cluster (BC)	1.000									
Links (BC)	−0.2550*	1.000								
	(0.000)									
Total link strength (BC)	−0.0743*	0.8247*	1.000							
	(0.025)	(0.000)								
Documents (BC)	−0.012	0.5640*	0.6158*	1.000						
	(0.724)	(0.000)	(0.000)							
Citations (BC)	0.048	0.3067*	0.3955*	0.5419*	1.000					
	(0.147)	(0.000)	(0.000)	(0.000)						
Cluster (C)	0.0677*	−0.1280*	−0.1691*	−0.029	−0.020	1.000				
	(0.041)	(0.000)	(0.000)	(0.391)	(0.551)					
Links (C)	−0.1736*	0.6046*	0.6042*	0.4524*	0.4900*	−0.2910*	1.000			
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)				
Total link strength (C)	−0.1730*	0.6022*	0.6250*	0.4925*	0.5053*	−0.2908*	0.9864*	1.000		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)			
Documents (C)	−0.012	0.5640*	0.6158*	1.0000*	0.5419*	−0.029	0.4524*	0.4925*	1.000	
	(0.724)	(0.000)	(0.000)	(0.000)	(0.000)	(0.391)	(0.000)	(0.000)		
Citations (C)	0.048	0.3067*	0.3955*	0.5419*	1.0000*	−0.020	0.4900*	0.5053*	0.5419*	1.000
	(0.147)	(0.000)	(0.000)	(0.000)	(0.000)	(0.551)	(0.000)	(0.000)	(0.000)	

Note: (BC), bibliographic coupling links; (C), citation links. *, Statistically significant at 5%.

Table 21
Matched observations from merged information associated with bibliographic coupling and citation links.

Result	Observations
not matched	253
from master	242 (_merge = = 1)
from using	11 (_merge = = 2)
matched	322 (_merge = = 3)

Table 22
Summary statistics from merged information associated with bibliographic coupling and citation links.

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Cluster (BC)	575	6	5	1	31
Links (BC)	575	31	39	1	307
Total link strength (BC)	575	115	302	1	3501
Documents (BC)	575	3	5	1	63
Citations (BC)	575	45	182	0	2683
Normalised citations (BC)	575	3	10	0	128
Average publication year (BC)	573	2015	6	1986	2023
Average citations (BC)	575	10	19	0	169
Average normalised citations (BC)	573	1	1	0	10
Cluster (C)	322	15	11	1	40
Links (C)	322	6	10	1	74
Total link strength (C)	322	11	24	1	203
Documents (C)	322	4	7	1	63
Citations (C)	322	75	239	0	2683
Normalised citations (C)	322	5	13	0	128
Average publication year (C)	321	2016	5	1986	2023
Average citations (C)	322	13	23	0	169
Average normalised citations (C)	321	1	1	0	9

Note: (BC), bibliographic coupling links; (C), citation links.

Table 23
Spearman's rank correlation for merged information associated with bibliographic coupling and citation links.

	Cluster (BC)	Links (BC)	Total link strength (BC)	Documents (BC)	Citations (BC)	Cluster (C)	Links (C)	Total link strength (C)	Documents (C)	Citations (C)
Cluster (BC)	1.000									
Links (BC)	−0.1875* (0.001)	1.000								
Total link strength (BC)	−0.097 (0.081)	0.9371* (0.000)	1.000							
Documents (BC)	0.006 (0.915)	0.6347* (0.000)	0.6411* (0.000)	1.000						
Citations (BC)	−0.023 (0.680)	0.4405* (0.000)	0.4661* (0.000)	0.6385* (0.000)	1.000					
Cluster (C)	0.1805* (0.001)	−0.075 (0.182)	−0.084 (0.132)	−0.009 (0.880)	−0.058 (0.298)	1.000				
Links (C)	−0.013 (0.823)	0.6742* (0.000)	0.7139* (0.000)	0.6371* (0.000)	0.6222* (0.000)	−0.1253* (0.025)	1.000			
Total link strength (C)	0.001 (0.988)	0.6724* (0.000)	0.7314* (0.000)	0.6498* (0.000)	0.6231* (0.000)	−0.109 (0.052)	0.9821* (0.000)	1.000		
Documents (C)	0.006 (0.915)	0.6347* (0.000)	0.6411* (0.000)	1.0000* (0.000)	0.6385* (0.000)	−0.009 (0.880)	0.6371* (0.000)	0.6498* (0.000)	1.000	
Citations (C)	−0.023 (0.680)	0.4405* (0.000)	0.4661* (0.000)	0.6385* (0.000)	1.0000* (0.000)	−0.058 (0.298)	0.6222* (0.000)	0.6231* (0.000)	0.6385* (0.000)	1.000

Note: (BC), bibliographic coupling links; (C), citation links. *, Statistically significant at 5%.

CRediT authorship contribution statement

Vítor João Pereira Domingues Martinho: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing –

review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

I am Associate Editor of the Heliyon Journal. This fact did not affect the peer-review process.

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