Loet Leydesdorff: bibliometric analysis and mapping of his scientific production

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Abstract

This study conducts a comprehensive bibliometric analysis and mapping of the scientific production of Loet Leydesdorff. Leveraging bibliometric techniques, the research aims to explore the breadth and impact of Leydesdorff's scholarly contributions. The analysis includes an examination of his publication patterns, citation impact, and collaborations over time. Additionally, mapping techniques will be employed to visually represent the networks and interdisciplinarity associated with Leydesdorff's work. The study provides insights into the evolution of his research interests, the influence of his contributions within the scientific community, and the interdisciplinary connections inherent in his body of work.

Keywords

Bibliometric analysis; Bibliometrics; *Biblioshiny*; *Web of Science*; *Cosma*; Text analysis; Social network analysis; Mapping; Researchers; Loet Leydesdorff.

Acknowledgements

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"Citation analysis has conquered the world of science policy analysis"
(**Amsterdamska**; **Leydesdorff**, 1988)

1. Introduction

Loet Leydesdorff was a Dutch sociologist of science and science communication researcher. He received his PhD in Sociology of Science from the *University of Amsterdam* in 1979 with a thesis entitled "Dynamic and stochastic models for reciprocal citation processes" (**Leydesdorff**, 1979). His research focused mainly on the application of complex systems theory to scientific communication.

Died in March 2023, Leydesdorff is internationally recognised for his contributions to the mapping and analysis of scientific collaboration networks. In (**Leydesdorff**, 2007a) he proposed the use of "intermediate centrality" as an indicator of the interdisciplinarity of scientific journals. Furthermore, his innovative methods for visualising and analysing networks, as shown in (**Leydesdorff**; **Ràfols**, 2009), offer a unique perspective on the global structure of scientific research.

> Leydesdorff is internationally recognised for his contributions to the mapping and analysis of scientific collaboration networks

Simultaneously, Leydesdorff developed sociological models of scientific communication. His book "*A sociological theory of communication: The self-organization of the knowledge-based society*", explores the dynamics of knowledge-based societies (**Leydesdorff**, 2001). He has also contributed to understanding the dynamics of scientific research, as evidenced in (**Leydesdorff**; **Meyer**, 2010), on the decline of university patents. Together with Henry Etzkowitz, he developed the Triple Helix model, a conceptual model that describes the interaction and collaboration between universities, industries and governments in the innovation process (**Etzkowitz**; **Leydesdorff**, 1996), with great repercussions in the area. The breadth of Loet Leydesdorff's contributions to the understanding of research networks, scientific communication, innovation and the sociology of science is noteworthy.

Bibliometric analysis is a macroscopic tool for extracting and discovering knowledge from a large amount of research literature very quickly compared to a traditional systematic review. In recent years, bibliometric analysis has attracted the interest of researchers for various reasons, such as the emergence of digital technologies or bibliometric software like *VOSviewer*, *CiteSpace* and *Biblioshiny* and the development of academic databases like *Web of Science*, *Scopus* and *Google Scholar* (**Moral**-**Muñoz** *et al.*, 2020).

Bibliometric analysis uses both quantitative and qualitative methods. Quantitative methods include descriptive and performance metrics of the research output of a field (the number of publications or citations, etc.), as well as the identification of the most important research constituents (the most cited articles, the most productive sources, etc.). Qualitative methods include the analysis of scientific mapping to explore the relationships between research constituents (**Donthu**, 2021). Scientific mapping is carried out by analysing networks of textual units, with techniques such as co-word analysis, co-citation analysis and collaboration analysis (**Zupic**; **Čater**, 2015).

This paper is structured as follows: section 2 presents the methodology used. Section 3 provides the results of the bibliometric analysis. Section 4 presents the interactive mapping analysis to explore the relationships between the elements studied (co-authors, keywords, keywords plus and publications). Finally, section 5 provides a brief summary of the main results and conclusions of the work.

2. Methodology

This section describes the research methodology used. The data were obtained from the *Web of Science* (*WoS*) *Core Collection* database, with the search phrase "L. Leydesdorff OR Loet Leydesdorff":
http://www.webofscience.com

Figure 1 gives an overview of the data corpus.

Based on them, a bibliometric analysis was carried out to answer the research questions, which involves, on the one hand, a statistical analysis and, on the other hand, the visualisation of the research production of a field. This bibliometric analysis was carried out using *Bibliometrix*, an open source software, supported by the *R* environment, which provides tools for the calculation of performance metrics (**Aria**; **Cuccurullo**, 2017):
https://www.bibliometrix.org/home

> Together with Henry Etzkowitz, he developed the Triple Helix model, a conceptual model that describes the interaction and collaboration between universities, industries and governments in the innovation process

Bibliometrix is integrated with *Biblioshiny*, a web interface for bibliometric network visualisation. The statistical analysis consisted of a performance analysis to show publication and citation patterns, publications, authors and countries, as well as the most cited articles. For visualisation, publications were mapped to explore topic and keyword trends through co-word analysis, co-citation clusters through co-citation analysis, and collaboration structure between countries through collaboration analysis. The latter results were visualised in the form of networks. The workflow steps followed for the bibliometric analysis were: study design, data collection, data analysis, and visualisation and interpretation of the results (**Zupic**; **Čater**, 2015).

The main objective is to examine and visualise Loet Leydesdorff's scientific publications from 1980 to 2023. The research questions of this study are as follows:

- What is the evolution of publications and citations?
- What are the most relevant and influential sources, countries and publications?
- What are the most common research topics and keyword trends in Leydesdorff research?
- What are the main co-citation clusters?
- What is the collaborative network of countries in social media research?

In addition, a scientific network cartography has been created, made up of this set of publications belonging to this author, with the idea of displaying it interactively on the web and with the possibility of downloading it. The software used for this has been *Cosma*, a software for the visualisation of documentary graphs (**Perret** *et al.*, 2021). In the section corresponding to the cartography we will explain in more detail its characteristics and functionalities.

The Table 1 presents a summary of the main information about the dataset. Specifically, our dataset contains 424 articles published between 1980 and 2023. These articles were published in 101 different scientific sources. The sources are made up of various types of documents: scientific journal articles, conference papers, books and book chapters, reviews, etc. The average number of years it takes for an article to be cited is approximately 0.92 and each article has on average 50.71 citations. The total number of references cited in all articles is 7486. In addition, the articles contain 3,297 author keywords and 1,470 plus (additional) keywords.

Table 1. Main information on the bibliographic dataset

Description	Results
Period	1980:2023
Sources (journals, books, etc.)	101
Documents	424
Annual growth rate	2,59
Average age of documents	13,5
Average number of citations per document	50,71
References	7486
Content of the documents	
Plus Keywords (ID)	423
Author Keywords (DE)	592
Authors	
Authors	197
Authors of single-authored documents	1
Collaboration of authors	
Single-authored documents	112
Co-authors per paper	2,27
International co-authorships %	57,78
Types of documents	
articles	314
articles; book chapters	9
article; conference proceedings	5
book review	6
proofreading	2
editorial material	23
letter	28
meeting summary	2
news	1
note	2
minutes	28
retraction	1
summary	3

Author keywords are keywords defined by authors to determine the content of their publications, while keywords plus are keywords generated by the *WoS* database from titles, keywords and abstracts of publications. Our dataset covers a number of single-authored publications of 112, and the rest were co-authored with a total of 197 co-authors. On average, each article is written by about 3 authors (i.e. authors per paper is 3.48). The collaboration rate is around 2.27 for the total set.

Figure 1 visually summarises the data presented in table 1.

Figure 1. Summary of the main information on the dataset

3. Results

This section presents and interprets the results of the bibliometric analysis based on the research questions of our study.

3.1. Evolution of publications and citations, sources, countries and most relevant publications.

Presented in this subsection are the results that answer the question: What is the evolution of Loet Leydesdorff's publications and citations on the research topics of his publications (Table 2 and Figure 2).

Table 2. Distribution of publications and citations

Year	Nº of publications	Total cites	Year	Nº of publications	Total cites	Year	Nº of publications	Total cites
1980	1	2	1996	4	124	2010	21	1.513
1981	1	3	1997	5	182	2011	26	1.323
1982	1	2	1998	5	504	2012	28	1.498
1984	1	2	1999	2	38	2013	30	1.048
1986	1	65	2000	8	3.843	2014	27	1.233
1987	5	143	2001	5	43	2015	27	978
1988	2	1	2002	4	79	2016	22	548
1989	5	255	2003	7	293	2017	19	462
1990	4	115	2004	5	220	2018	12	201
1991	4	92	2005	11	1.097	2019	21	260
1992	5	40	2006	15	1.443	2020	11	65
1993	3	126	2007	15	691	2021	9	64
1994	7	155	2008	15	1.042	2022	4	40
1995	2	12	2009	21	1.463	2023	3	4

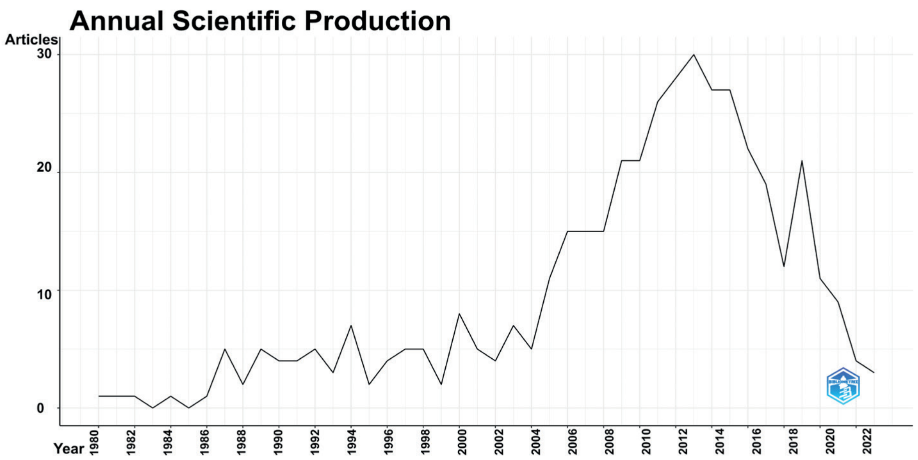


Figure 2. Annual scientific production

Table 2 shows the distribution of publications and citations for the 43-year period between 1980 and 2023. The highest number of publications is between 2006 and 2019, representing 66% (280) of the total number of publications. In the years 2020 to 2023, there was a decrease in the number of publications compared to the previous years.

Below are presented the results to answer the question: What are Leydesdorff's most relevant sources, countries and publications? Table 3 and Figure 3 present the 10 scientific journals where he published the most. These journals cover 64.1% of the total number of publications in our dataset. The top three journals that cover articles in Leydesdorff's research areas are *Scientometrics*, *Journal of the American Society for Information Science and Technology* and *Journal of informetrics*.

Table 3. Top 10 scientific journals where Loet published more

Sources	Articles
Scientometrics	93
Journal of the American Society for Information Science and Technology	55
Journal of informetrics	45
Journal of the Association for Information Science and Technology	28
Research policy	15
Profesional de la información	10
Social science information sur les sciences sociales	8
Technological forecasting and social change	7
Systems research and behavioral science	6
17th International conference on scientometrics & informetrics (ISSI2019), vol. 1	5

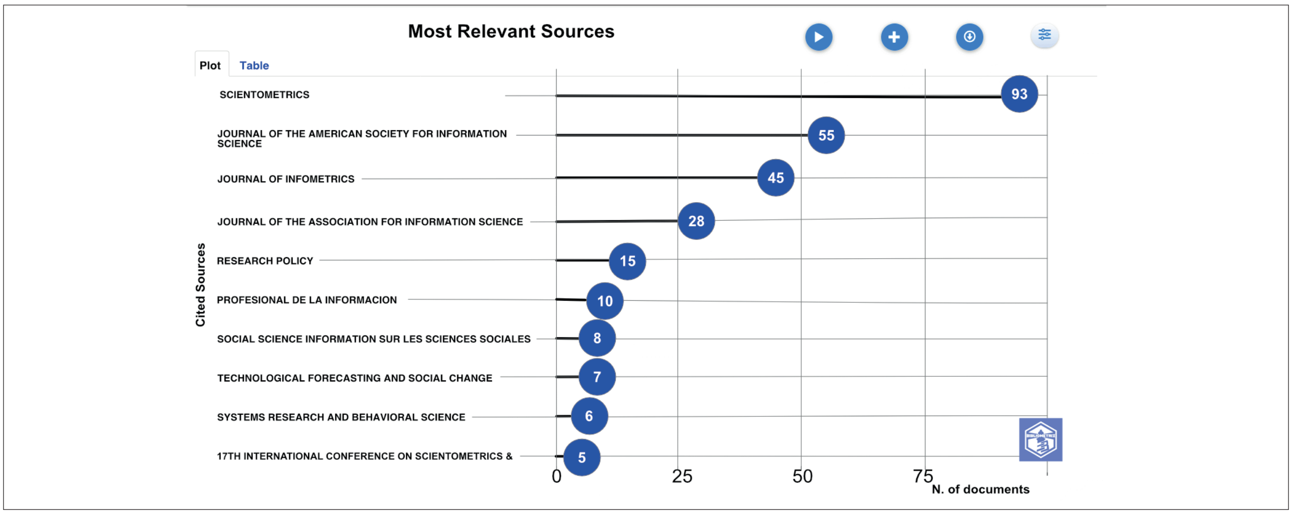


Figure 3. Top 10 scientific journals where Loet published more

Table 4 shows the top 10 most cited journals in the field. The most cited journals in the field measure the number of citations in the field received per cited reference within the reference lists of the publications in the dataset. From these results, we can see that *Scientometrics* is the most cited source among researchers. This source has been cited 1886 times. The second most cited source is *Journal of the American Society for Information Science and Technology* (1243 times), followed by *Research Policy* (887 times). This shows that these journals are the main references for publications by this author and his co-authors.

Table 4. The most cited journals in the field

Sources	Articles
Scientometrics	1886
Journal of the American Society for Information Science and Technology	1558
Research policy	887
Journal of informetrics	661
Science	236
Social networks	184
Journal of the Association for Information Science and Technology (Jasist)	173
Nature	160
Social studies of science	160
Social science information	141

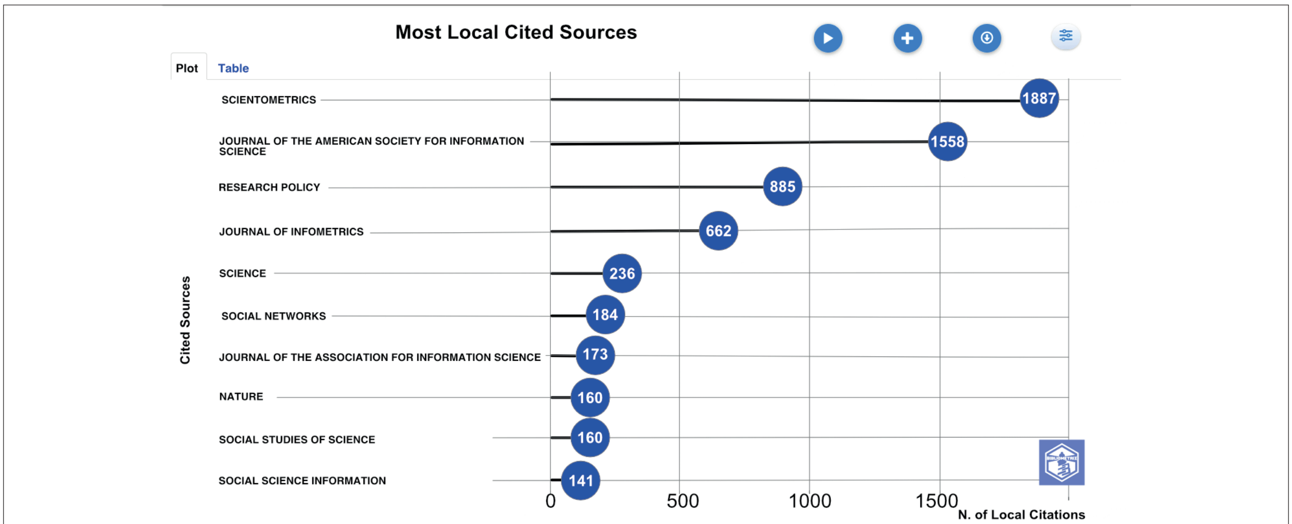


Figure 4. The most cited journals in the field.

Table 5 presents the top 10 most influential publications in terms of total citations. The total number of citations of a journal is the number of citations received by the articles published in that journal in the dataset. From these results it can be seen that the top three journals, *Journal of the American Society for Information Science and Technology*, *Scientometrics* and *Journal of informetrics*, have published many articles that have received a high number of total citations with a high h-index.

However, there are also magazines, such as *Journal of the Association for Information Science and Technology* and *Research Policy et Social Science*, which have a high number of citations with a limited number of articles published in Leydesdorff's publications.

Table 5. Top 10 most influential journals by total citations

Journals	h index	g index	m_index	Total citations	Number of publications	Start year
Journal of the American Society for Information Science and Technology	36	55	1,565	4388	55	2001
Scientometrics	34	56	0,791	3491	93	1981
Journal of informetrics	27	45	1,688	2.41	45	2008
Journal of the Association for Information Science and Technology	18	28	1,8	1102	28	2014
Research policy	14	15	0,35	5937	15	1984
Social science information sur les sciences sociales	7	8	0,219	101	8	1992
Technological forecasting and social change	7	7	0,368	254	7	2005
Profesional de la informacion	6	10	0,375	172	10	2008
Plos one	5	5	0,357	276	5	2010
Journal of data and information science	4	4	0,571	55	4	2017

Table 6 shows the data for the 20 countries where this author has published the most; SCP stands for *Single Country Publication* (refers to scientific publications originating from a single country. That is, all the main authors or affiliations are located in a single country); MCP is *Multiple Country Publication* (refers to scientific publications involving collaboration of authors or affiliations from several countries) *MCP ratio* (this is the measure that indicates the proportion of the total number of publications that are collaborative between authors or affiliations from different countries.

These results show that between the Netherlands and Germany, 299 articles have been published and 98 of them involved international collaborations. The third country with the highest number of publications is the United States, with 23 international collaborations.

However, some observations can be made about the proportion of CCMs. Countries such as Germany, China and the UK have a higher degree of international collaboration than other countries.

Table 6. The 20 most frequent countries of origin of authors and co-authors of publications

Country	Articles	SCP	MCP	Freq	MCP_Ratio
Netherlands	258	160	98	0,608	0,38
Germany	41	0	41	0,097	1,00
USA	25	2	23	0,059	0,92
China	22	0	22	0,052	1,00
United Kingdom	17	0	17	0,040	1,00
Russia	8	0	8	0,019	1,00
Korea	7	0	7	0,017	1,00
Switzerland	6	1	5	0,014	0,83
Belgium	4	0	4	0,009	1,00
Italy	3	0	3	0,007	1,00
Colombia	2	0	2	0,005	1,00
France	2	1	1	0,005	0,50
Hungary	2	0	2	0,005	1,00
India	2	0	2	0,005	1,00
Norway	2	0	2	0,005	1,00
Australia	1	0	1	0,002	1,00
Cuba	1	0	1	0,002	1,00
Finland	1	0	1	0,002	1,00
Ireland	1	0	1	0,002	1,00

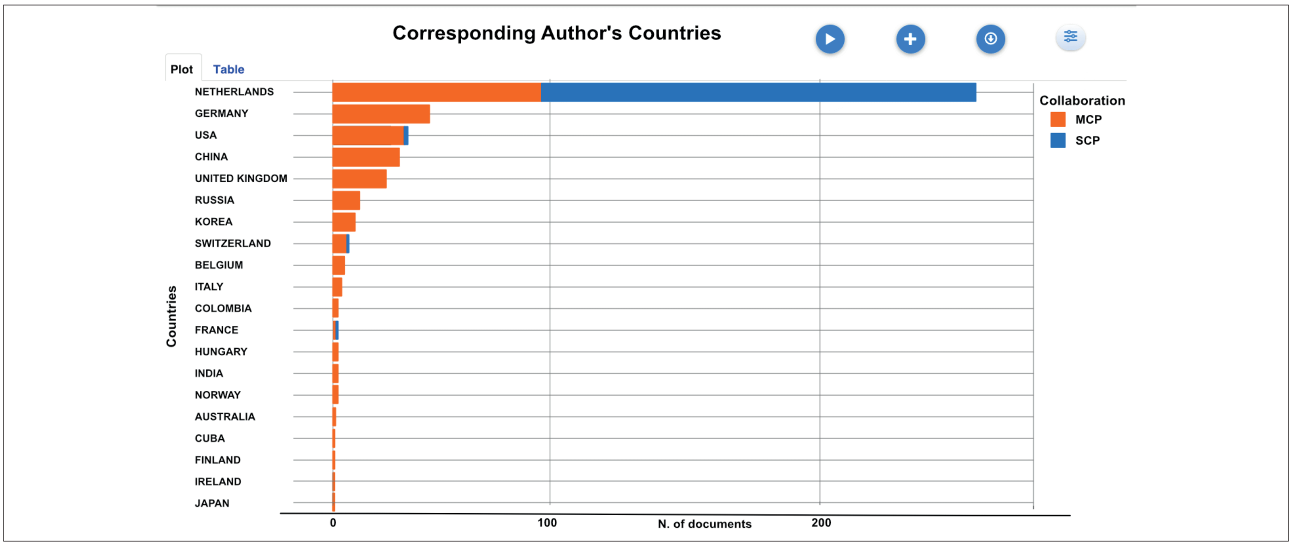


Figure 5. Top 20 countries of origin of authors and co-authors of publications

Finally, Table 7 presents the ranking of Leydesdorff's most cited articles.

Table 7. Ranking of most cited publications

Lead author – *Publication*	Title	Total citations
Etzkowitz H, 2000, *Res policy*	The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university-industry-government relations *10.1016/S0048-7333(99)00055-4*	3,491
Wagner CS, 2005, *Res policy*	Network structure, self-organization, and the growth of international collaboration in science. *10.1016/j.respol.2005.08.002*	614
Mingers J, 2015, *Eur J Oper Res*	A review of theory and practice in scientometrics. *10.1016/j.ejor.2015.04.002*	426
Leydesdorff L, 2009, *J AM SOC INF SCI TEC*-a-b-c	A global map of science based on the ISI subject categories. *10.1002/asi.20967*	393
Zhou P, 2006, *Res policy*	The emergence of China as a leading nation in science. *10.1016/j.respol.2005.08.006*	385
Leydesdorff L, 2007, *J AM SOC INF SCI TEC*	Betweenness centrality as an indicator of the interdisciplinarity of scientific journals. *10.1002/asi.20614*	347
Ràfols I, 2012, *Res policy*	How journal rankings can suppress interdisciplinary research: A comparison between Innovation Studies and Business & Management. *10.1016/j.respol.2012.03.015*	335
Leydesdorff L, 2012, *J Knowl Econ*	The Triple Helix, Quadruple Helix, …, and an N-Tuple of Helices: Explanatory models for analyzing the knowledge-based economy? *10.1007/s13132-011-0049-4*	307
Ràfols I, 2010, *J AM SOC INF SCI TEC*	Science overlay maps: A new tool for research policy and library management	290
Leydesdorff L, 2006, *J AM SOC INF SCI TEC*	Co-occurrence matrices and their applications in information science: Extending ACA to the web environment	270

As can be seen in the results of Table 7, the article "*The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university-industry-government relations*" (**Etzkowitz**; **Leydesdorff**, 2000) has received the highest number of citations, followed by the article "*Network structure, self-organization, and the growth of international collaboration in science*" (**Wagner**; **Leydesdorff**, 2005) y "*A review of theory and practice in scientometrics*" (**Mingers**; **Leydesdorff**, 2015). Based on the content analysis of the best research articles, three themes are identified: 3 of the 10 articles focused on the Triple Helix, 3 of the 10 focused on scientometrics, and 1 of the 10 focused on a global map of science. (**Leydesdorff**; **Ràfols**, 2009).

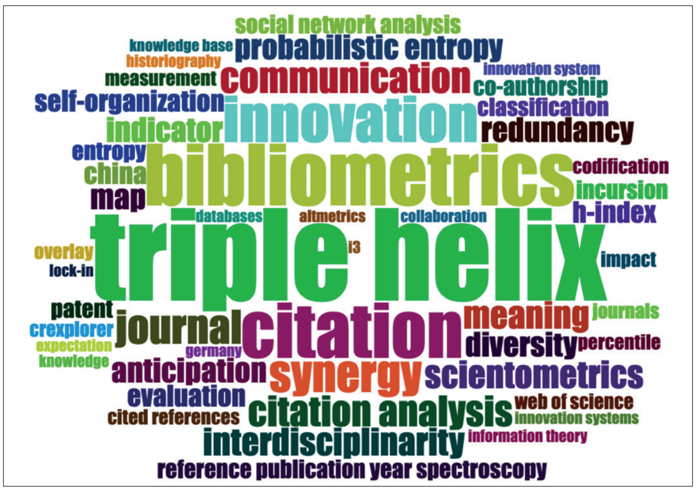


Figure 6. Word cloud based on author keywords

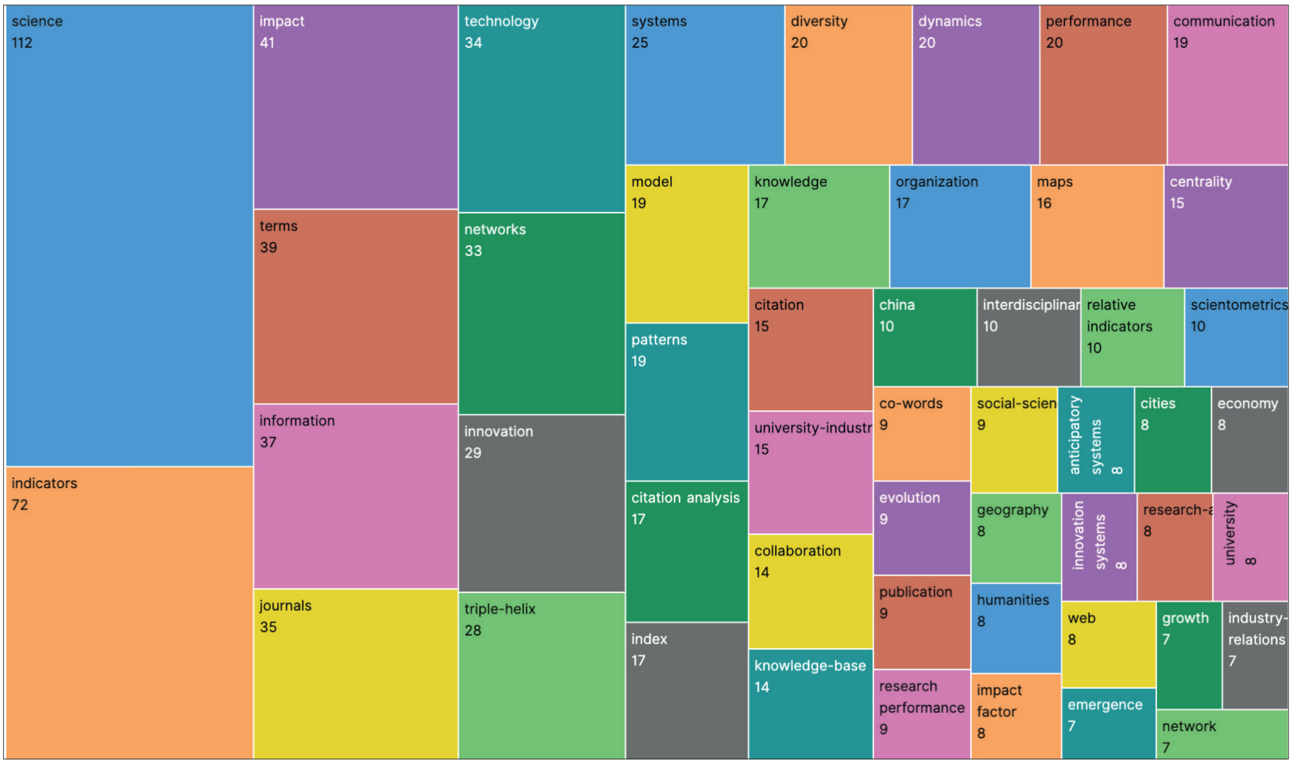


Figure 7. Keywords plus treemap.

3.2. Research topics and keyword trends

In this section we present the results to answer the question: what are the most common research topics and keyword trends in Leydesdorff publications? We present a thematic analysis to detect the main research topics in the field using a word cloud and a word treemap.

Figure 6 shows the word cloud for the 50 most common author keywords in the collection of publications. The size of the keyword in the figure indicates the frequency of the keyword in the dataset. As can be seen in the figure, the most frequently used words determine the content of most of the studies in the collection. More specifically, the frequent keyword "triple helix" is the main theme, as the papers in the collection address various aspects of the triple helix of knowledge production, university-industry-government relations and perspectives on innovation systems. The keywords "bibliometrics", "citation analysis", "scientometrics", "social network analysis", "cited references" and "evaluation" show

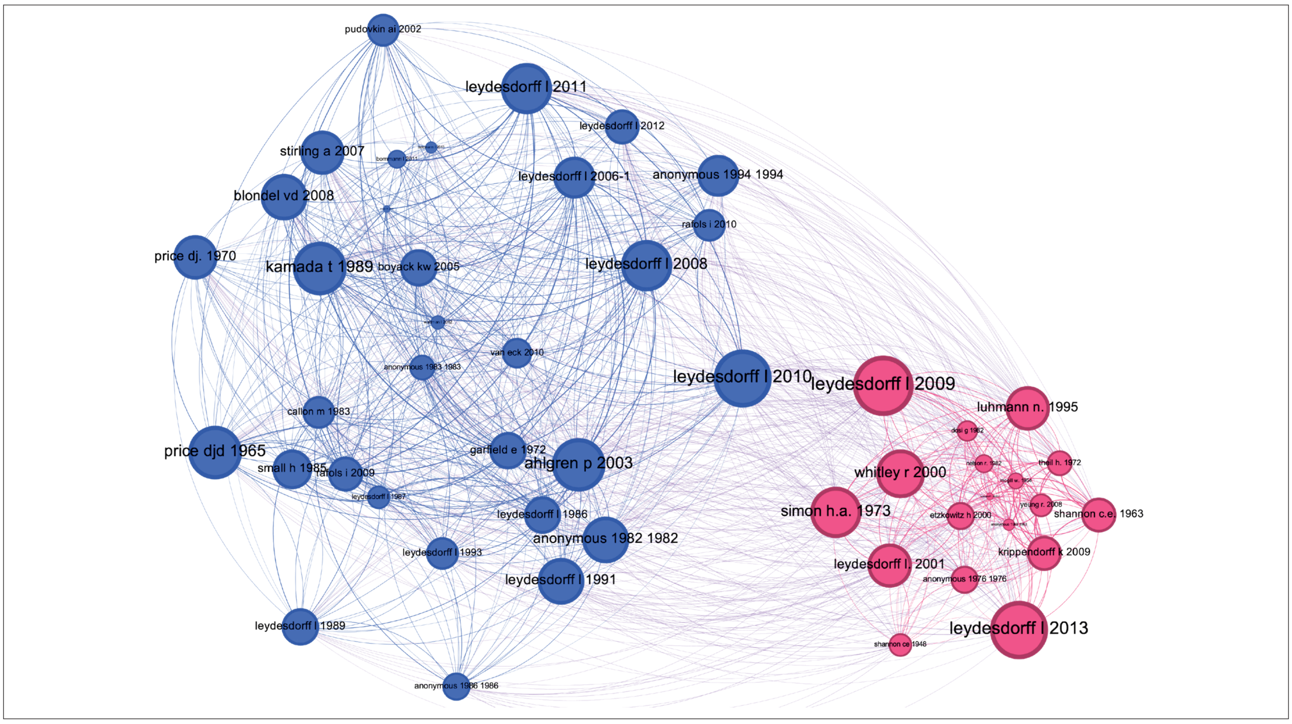


Figure 8. Leydesdorff's publication co-citation network

Figure 9. Map of collaboration between authors from different countries

their importance and represent the main methodologies according to their conceptual meaning in Leydesdorff's publications and research.

The 50 most commonly used keywords in articles are presented in the form of a Treemap of words. The Treemap in Figure 7 highlights the combination of plus keywords, indicating triple helix and bibliometrics. "Triple helix" is the most used keyword, while "lock-in" is the least used. Focusing on the keywords, other research areas that were of interest are science, indicators, network maps, innovation and interdisciplinarity.

3.3. Co-citation network

In this subsection, results are presented to answer the question: What are the main groups of co-citations related to Leydesdorff's publications?

Figure 8 shows the co-citation network, a type of network in which nodes represent scientific papers and links between nodes indicate that these papers have been cited together in the same reference work. This network was conducted with a minimum degree of co-citation equal to three and a threshold of 50 network nodes. The nodes were labelled with the first author and the year of publication of the article, while the network link is the co-citation between two documents. The node size indicates the number of citations received by the papers and the link thickness represents the strength of the co-citation links. The colour of the node shows the cluster with which the article is associated, in our case two: one related to bibliometrics and the other to scientific innovation.

3.4. Networking between countries

In this subsection, results are presented to answer the question: what is the network of collaboration between authors from different countries in Leydesdorff's research?

Figure 9 shows such a map of international collaboration. It depicts the publication output of authors from each country and the collaboration between authors from different countries. Countries with a darker colour indicate more publications than countries with a lighter colour, while the thickness of the lines represents stronger collaborations between countries.

Figure 10 shows the collaborative social network at country level in detail. The node in the network represents the country and the link between two nodes represents the cooperation between countries. The size of the country indicates the degree of cooperation, and the

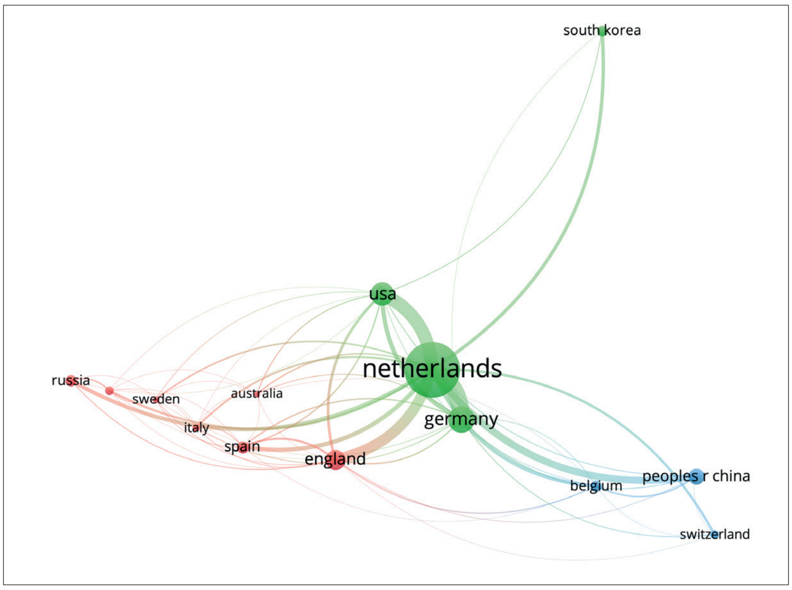


Figure 10. Cross-country collaboration network (graph generated with *VOSwiever*)

thickness of the link indicates the closeness of the collaboration between countries. It is worth highlighting the collaboration with authors from our country, consistent with the high number of publications by this author in the journal *Profesional de la información*.

4. Mapping scientific networks

The concept of "scientific network mapping" refers to the process of visualising and analysing the relationships and connections between different elements within the scientific domain, such as researchers, institutions, or subject areas. This practice uses network analysis tools to graphically represent the structure and dynamics of interactions in the scientific community.

In the context of scientific research, network mapping can reveal patterns of collaboration, identify centres of influence, and provide information on the interconnectedness between disciplines or areas of study. Methods employed include social network analysis, where nodes represent entities such as researchers or institutions, and links between nodes represent collaborative relationships, citations, or any other form of relevant interaction.

This approach helps to understand the structure and evolution of scientific communities, facilitating the identification of key research areas, the assessment of the impact of researchers and institutions, and the visualisation of interdisciplinarity in scientific production. Scientific network mapping is valuable for analysing and communicating the complexity of interactions in academia.

4.1. Leydesdorff publications on scientific network mapping

Loet Leydesdorff is recognised for his significant contributions to the mapping of scientific networks (29 publications, see Table 8). He has developed innovative methodologies and tools to analyse and visualise the structure of scientific collaborations at different scales. Here are some key points about his work in this field:

1. *Intermediation centrality*: In his 2007 article, Leydesdorff proposes the use of "betweenness centrality" as an indicator of the interdisciplinarity of scientific journals. Betweenness centrality measures the frequency with which a node is on the shortest path between two other nodes in a network. He applied this measure to assess how scientific journals can serve as bridges between different disciplines, providing a means to map interdisciplinary connections (**Leydesdorff**, 2007a).

2. *Social network analysis*: Leydesdorff used social network analysis methods to explore collaborations between researchers and institutions. These analyses can visually map connections and relationships between actors in the scientific domain, revealing network structure and key points of collaboration.

3. *Bibliometric indicators*: In addition to mapping collaborations, Leydesdorff has developed bibliometric indicators to assess the impact and visibility of researchers and institutions. These indicators can be used to understand the distribution of collaborations and the influence of publications within the scientific network.

4. *Network visualisation*: In his 2009 paper, Leydesdorff presented visualisation methods for graphically representing scientific networks. These visualisations offer an intuitive insight into the distribution of collaborations and the overall structure of the scientific research network. (**Leydesdorff**; **Ràfols**, 2009).

Table 8. Leydesdorff's most relevant publications related to "mapping scientific networks"

Thematic area	Subject - Cite
Patent portfolio analysis of cities: statistics and maps of technological inventiveness	Cities and knowledge-based economy (**Kogler**; **Heimeriks**; **Leydesdorff**, 2018)
Betweenness and diversity in journal citation networks as measures of interdisciplinarity - A tribute to Eugene Garfield	Interdisciplinary journal ranking (**Leydesdorff**; **Wagner**; **Bornmann**, 2018)
Mapping patent classifications: portfolio and statistical analysis, and the comparison of strengths and weaknesses	Cooperative patent classifications (CPC) (**Leydesdorff**; **Kogler**; **Yan**, 2017)
Journal portfolio analysis for countries, cities, and organizations: Maps and comparisons	*Web of Science* data for portfolio analysis (**Leydesdorff**; **Heimeriks**; **Rotolo**, 2016)
Journal maps, interactive overlays, and the measurement of interdisciplinarity on the basis of *Scopus* data (1996-2012)	Global map of science using *Scopus* (**Leydesdorff**; **De-Moya-Anegón**; **Guerrero-Bote**, 2015)
International collaboration in science: the global map and the network	Global network of international co-authorship (**Leydesdorff**; **Wagner**; **Park**; **Adams**, 2013)
Betweenness centrality as a driver of preferential attachment in the evolution of research collaboration networks	Preferential attachment in coauthorship networks (**Abbasi**; **Hossain**; **Leydesdorff**, 2012)
Mapping (*USPTO*) patent data using overlays to *Google Maps*	Patent-based *Google Maps* (**Leydesdorff**; **Bornmann**, 2012)
Mapping excellence in the geography of science: An approach based on *Scopus* data	Mapping centers of excellence worldwide (**Bornmann**; **Leydesdorff**; **Walch-Solimena**; **Ettl**, 2011)
'Meaning' as a sociological concept: A review of the modeling, mapping and simulation of the communication of knowledge and meaning	Discursive knowledge and communication (**Leydesdorff**, 2011)

Thematic area	Subject - Cite
The semantic mapping of words and co-words in contexts	Measuring semantics using latent semantic analysis (**Leydesdorff**; **Welbers**, 2011)
Science overlay maps: A new tool for research policy and library management	Science overlay maps for benchmarking (**Rafols**; **Porter**; **Leydesdorff**, 2010)
Mapping the geography of science: Distribution patterns and networks of relations among cities and institutes	Overlaying scientific networks on geographic maps (**Leydesdorff**; **Persson**, 2010)
Maps on the basis of the *Arts & Humanities Citation Index*: The journals *Leonardo* and *Art journal* versus "digital humanities" as a topic	Mapping *Arts & Humanities Citation Index* (*A&HCI*) (**Leydesdorff**; **Salah**, 2010)
Journal maps on the basis of *Scopus* data: A comparison with the *Journal Citation Reports* of the *ISI*	Comparing *Scopus* and *Journal Citation Reports* (**Leydesdorff**; **De-Moya-Anegón**; **Guerrero-Bote**, 2010)
Knowledge linkage structures in communication studies using citation analysis among communication journals	Mapping communication studies (**Park**; **Leydesdorff**, 2009)
Dynamic animations of journal maps: Indicators of structural changes and interdisciplinary developments	Dynamic analysis of structural change in sciences (**Leydesdorff**; **Schank**, 2008)
Korean journals in the *Science Citation Index*: What do they reveal about the intellectual structure of S&T in Korea?	South Korea's research output (**Park**; **Leydesdorff**, 2008)
Betweenness centrality as an indicator of the interdisciplinarity of scientific journals	Centrality measures in journal citation networks (**Leydesdorff**, 2007a)
Mapping interdisciplinarity at the interfaces between the science citation index and the social science citation index	Combining journal citation reports (**Leydesdorff**, 2007)
Clustering methodologies for identifying country core competencies	Mexican science and technology literature (**Kostoff**; **Del-Río**; **Cortés**; **Smith**; **Smith**; **Wagner**; **Leydesdorff**; **Karypis**; **Malpohl**; **Tshiteya**, 2007)
Mapping the *Chinese Science Citation Database* in terms of aggregated journal-journal citation relations	Mapping *Chinese Science Citation Database* (**Leydesdorff**; **Jin**, 2005)
Mapping the *Chinese Science Citation Database*	Mapping *Chinese Science Citation Database* (alternative abstract) (**Leydesdorff**; **Bihui**, 2004)
Clusters and maps of science journals based on bi-connected graphs in *Journal Citation Reports*	Decomposing journal-journal citation matrix (**Leydesdorff**, 2004)
Why words and co-words cannot map the development of the sciences	Word co-occurrence analysis in biochemistry (**Leydesdorff**, 1997)
Mapping change in scientific specialties: A scientometric reconstruction of the development of artificial intelligence	Emergence of artificial intelligence as a discipline (**Van-den-Besselaar**; **Leydesdorff**, 1996)
Tracking areas of strategic importance using scientometric journal mappings	Indicators for tracking emerging developments (**Leydesdorff**; **Cozzens**; **Van-den-Besselaar**, 1994)
Various methods for the mapping of science	(**Leydesdorff**, 1987)

4.2. The *Cosma* software

Cosma[1] (*https://cosma.arthurperret.fr*) was developed as part of the *ANR HyperOtlet* programme, which aimed to represent Paul Otlet's social network in the form of an interactive graph, known as *Otletosphere* (*https://hyperotlet.huma-num.fr/otletosphere*). *Cosma* was developed by Guillaume Brioudes, Olivier Le Deuff and other collaborators in 2021.

It is a free experimental research tool, published under a free licence, which offers an innovative way to visualise and explore documentary networks.

Main features of *Cosma*:

1. Graph visualisation: allows the visualisation of an interactive documentary graph. The nodes of the network represent countries and the links between the nodes represent the cooperation between the authors of these countries.

2. Navigation functionalities: *Cosma*'s interface is divided into three zones. A panel on the left contains navigation functions such as search, index and display filters. On the right, a panel displays the selected record with a bibliography automatically generated from the sources cited in the text of the record.

3. Data export: Unlike most visualisation tools, *Cosma* inverts the usual logic. The application part, called cosmograph, is a simple creation form. The created export, an HTML file called cosmoscope, constitutes the actual visualisation interface. This HTML file can be exported, used and shared independently.

4. Discussion support: *Cosmoscope* files can be shared, making them a support for discussion in the context of a research or teaching assignment.

5. Recognition of categorisation: *Cosma* recognises, from a previous analysis, the categorisation of the cards and associates graphic codes (colours, layouts) and interactions (filtering of displayed elements) to them.

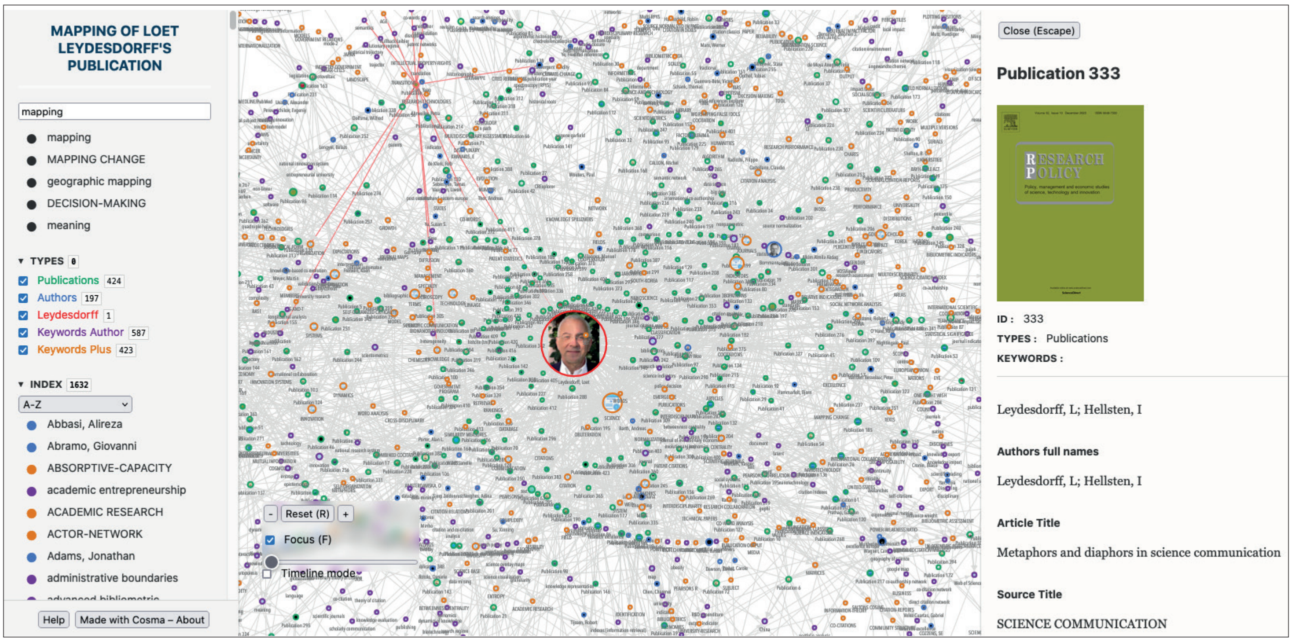


Figure 11. *Cosma* interface
https://cosma.arthurperret.fr

4.3. Stages of analysis of Loet Leydesdorff's mapping of scientific networks

Scientific mapping attempts to find representations of the intellectual connections within the dynamically changing system of scientific knowledge (**Small**, 1997). In other words, scientific mapping shows the structural and dynamic aspects of scientific research (**Cobo** *et al.*, 2011). In this paper we have developed a mapping of the publications of L. Leydesdorff who, throughout his career, has been one of the pioneers of this type of research.

The scientific mapping we have produced is a visual representation of how disciplines, fields, documents, co-authors, author words and index words (*keywords plus*) relate to each other in Leydesdorff publications.

In this section we describe the different stages of analysis of this mapping:

(a) *Source of data*: For this mapping, publication data were retrieved from the *Web of Science* (*WoS*) *Core Collection* database. Our dataset contains 424 articles published between 1980 and 2023.

(b) *The units of analysis*: From the 424 documents we selected the references of the publications, the co-authors, the title, the abstract. In addition, we selected the original keywords of the documents (author keywords) and the indexing keywords provided by the database (*ISI Keywords Plus*) as words to be analysed. We also took the *WoS* subject categories, the Orcid of the co-authors and the DOI of the publication.

(c) *Data pre-processing*: A scientific mapping analysis cannot be applied directly to data retrieved from bibliographic sources, i.e. a pre-processing of the retrieved data is necessary. Thus, the pre-processing of the data has been as follows:

- The correction and addition of the names of certain co-authors, and the inclusion of their photo in the database.
- Detection of duplicate elements and misspellings of co-authors and author words and index words.
- The division of the articles into different time sub-periods, in order to analyse the evolution of Leydesdorff's research (see table).

(d) *Standardisation process*: The *Cosma* software uses a specific visualisation algorithm to graphically represent the relationships between documentary elements. This algorithm is called a "*cosmograph*".

(e) *Methods of analysis:* Before applying the visualisation, *Cosma* performs a preliminary analysis to categorise the document files. This analysis determines the assignment of graphic codes such as colours and layouts.

(f) *Display algorithm*: force-layout algorithm, which *Cosma* incorporates.

As a final result, our Leydesdorff cosmoscope is available for use at this URL:
http://metroteach.com/Leydesdorff/index.html

It can be downloaded by clicking on the link Made with *Cosma* - About at the bottom left of the interface.
http://metroteach.com/Leydesdorff/cosmoscopio.html

The interface allows switching to a timeline visualisation (Table 9) to show the changes that occur with this variable (by clicking on the Timeline mode checkbox).

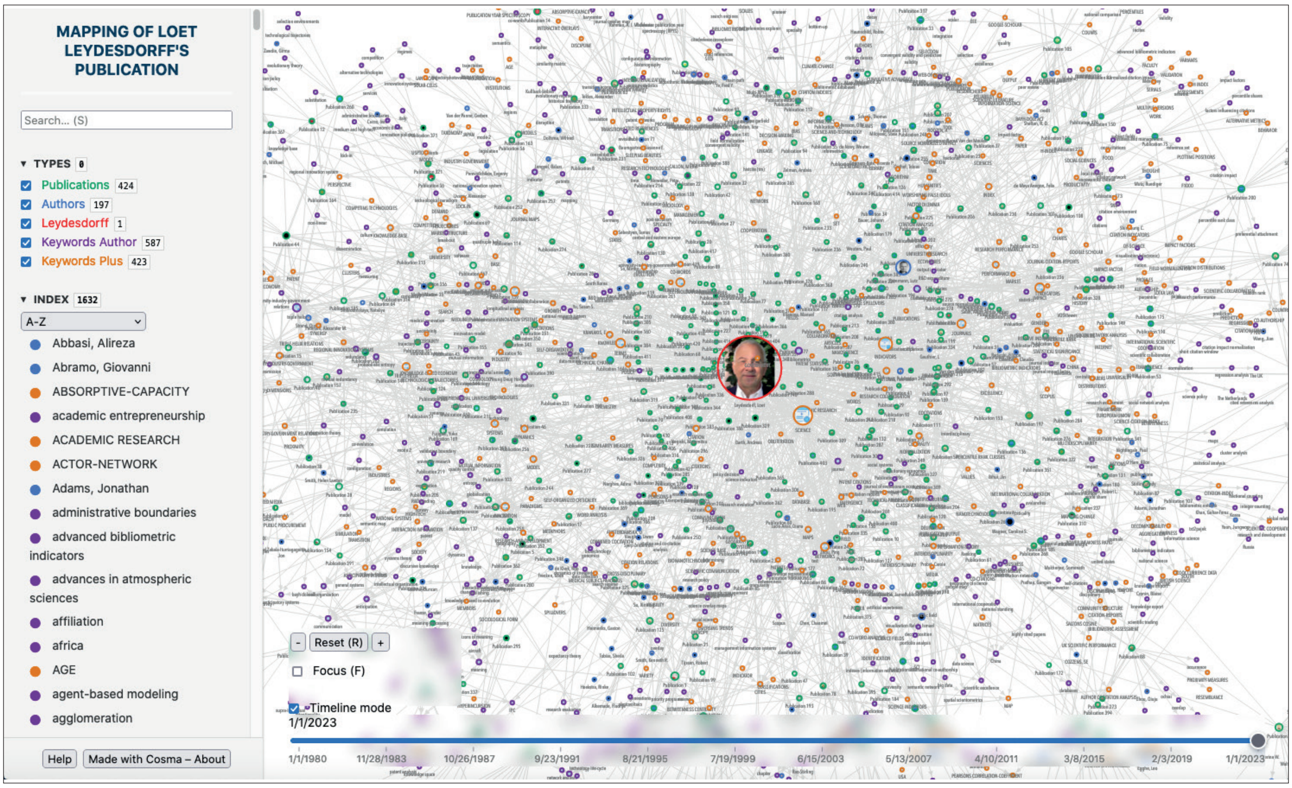


Figure 12. Scientific network mapping of Leydesdorff's publications.
http://metroteach.com/Leydesdorff/index.html

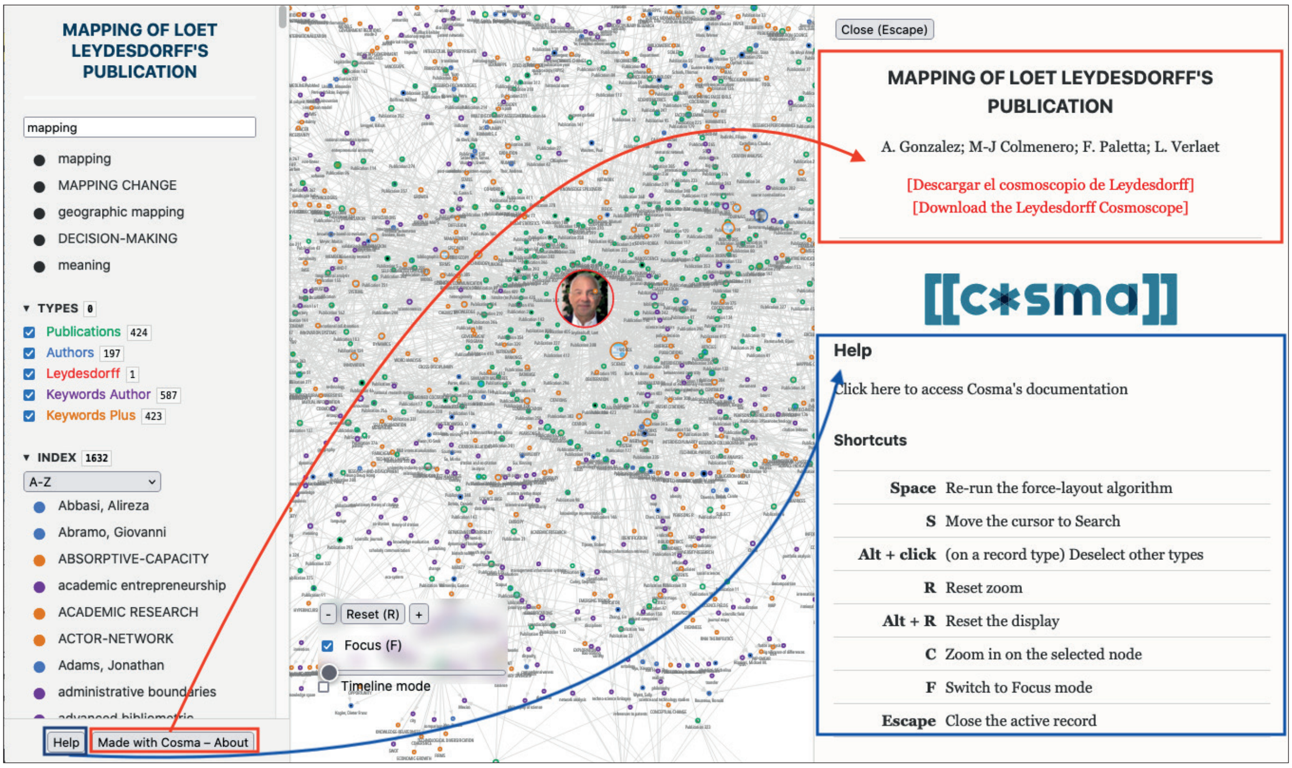


Figure 13. Discharge line of the Leydesdorff cosmoscope.
http://metroteach.com/Leydesdorff/cosmoscopio.html

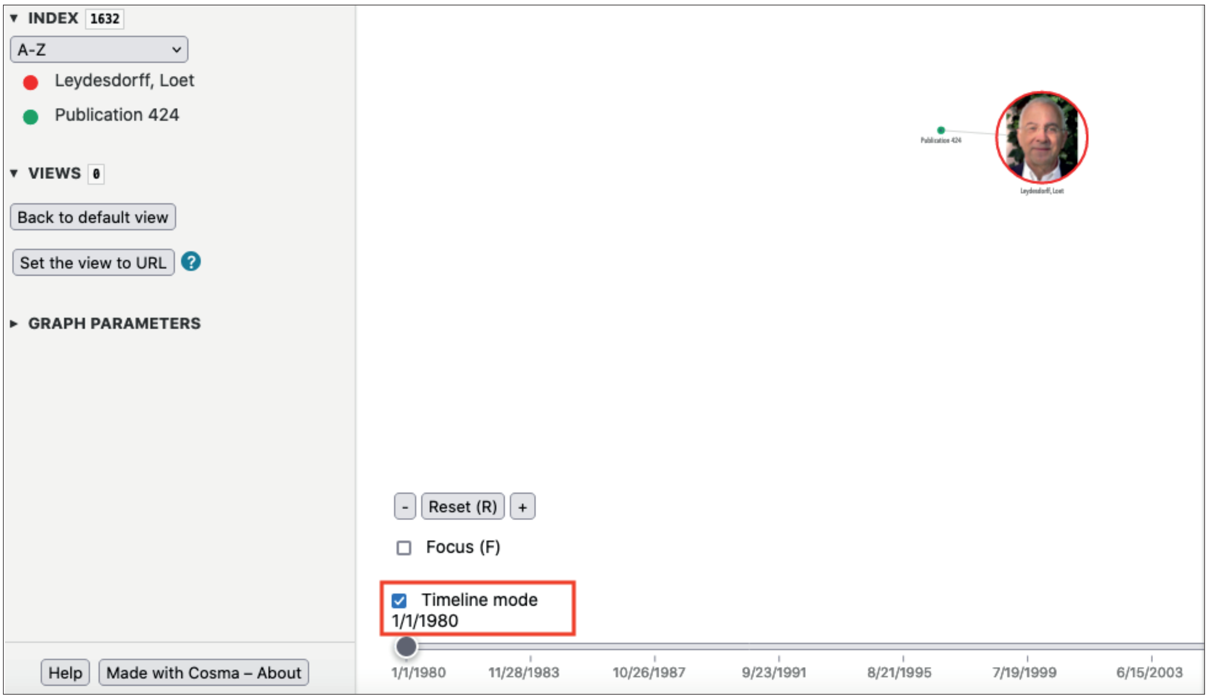
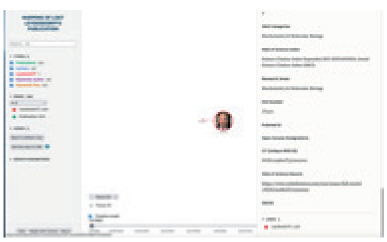
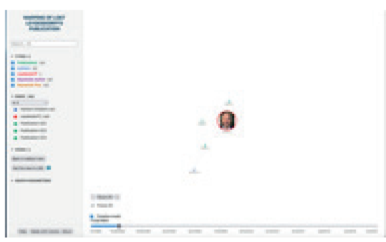
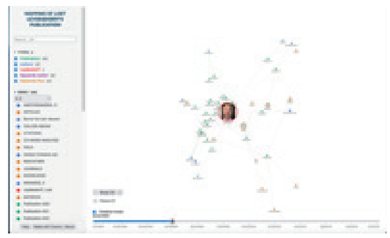
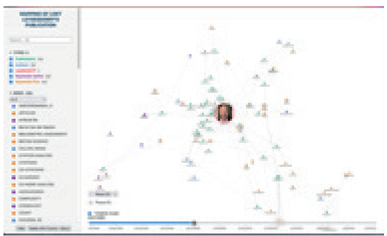
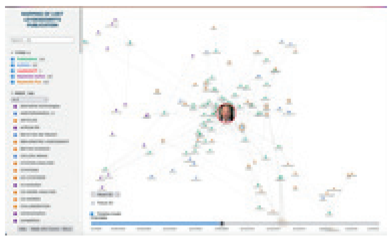
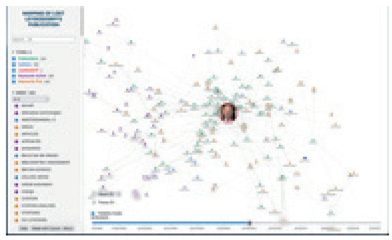
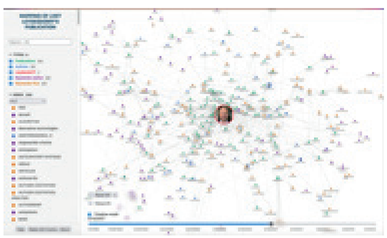
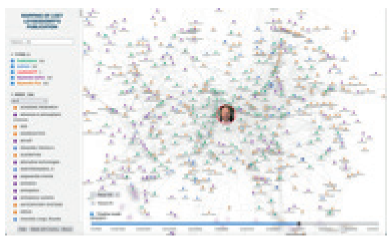
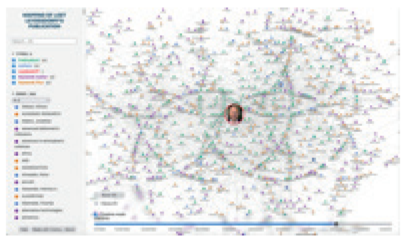
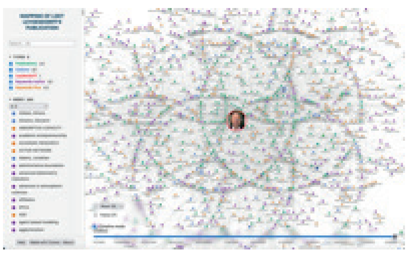
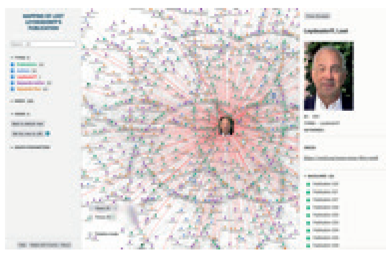
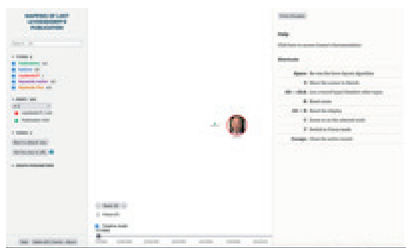


Figure 14. Leydesdorff cosmoscope "timeline" option

Table 9. Timeline of publications

		
1980	1983	1987
		
1995	1999	2003
		
2007	2011	2015
		
2019	2023	Ayuda de *Cosma*

5. Conclusions

A bibliometric analysis of Leydesdorff's publications collected in *WoS* has been carried out and a scientific mapping of his papers, including co-authors, their countries of origin and keywords (author and indexing), has also been produced.

The literature review on Loet Leydesdorff highlights his significant contributions to the sociology of science, bibliometric analysis, science communication and scientific network mapping. His work continues to influence and guide research in these areas, demonstrating the breadth of his intellectual impact.

For the mapping of scientific output we have included different methods of analysis (although some of them are common), which allowed us to discover the different facets of the knowledge investigated by Leydesdorff. Since the visualisations are different in each of them, different views of the field can be generated to help interpret and analyse the results. This cooperation between tools leads to a positive synergy, which allows extracting the knowledge hidden behind the data.

Our work has been intended as a small tribute to this recently deceased scientist, who has contributed to the advancement of several areas of study. We believe that a more complete scientific mapping analysis of Leydesdorff's work should be carried out, including the publications that *WoS* does not include, in order to compile all the knowledge, important theoretical contributions and the different perspectives (intellectual, social or conceptual) of the author's different areas of research.

6. Note

1. The name *Cosma* comes from Cosmas Rosellius, a Florentine Dominican monk, author of a *Thesaurus artificiosæ memoriæ* (1579), which translates as "treasure of artificial memory". A feature of Rossellius' book is the mnemonic verses given to help memorize orders of places, whether orders of Hell, or the order of the signs of the zodiac.
https://archive.org/download/thesaurusartifi00padogoog/thesaurusartifi00padogoog.pdf

7. References

Abbasi, Aliresa; **Hossain, Liaquad**; **Leydesdorff, Loet** (2012). "Betweenness centrality as a driver of preferential attachment in the evolution of research collaboration networks". *Journal of informetrics*, v. 6, n. 3.
https://doi.org/10.1016/j.joi.2012.01.002

Aria, Massimo; **Cuccurullo, Corrado** (2017). "Bibliometrix: An R-tool for comprehensive science mapping analysis". *Journal of informetrics*, v. 11, n. 4.
https://doi.org/10.1016/j.joi.2017.08.007

Bornmann, Lutz; **Leydesdorff, Loert**; **Walch-Solimena, Christiane**; **Ettl, Christoph** (2011). "Mapping excellence in the geography of science: An approach based on Scopus data". *Journal of informetrics*, v. 5, n. 4.
https://doi.org/10.1016/j.joi.2011.05.005

Cobo, Manuel J.; **López-Herrera, Antonio-Gabriel; Herrera-Viedma, Enrique**; **Herrera, Francisco** (2011). "Science mapping software tools: Review, analysis, and cooperative study among tools". *J. Assoc. Inf. Sci. Technol.*, v. 62, pp. 1382-1402.

Donthu, Naveen; **Kumar, Satish**; **Mukherjee, Debmalya**; **Pandey, Nitesh**; **Lim, Weng-Marc** (2021). "How to conduct a bibliometric analysis: An overview and guidelines". *Journal of business research*, v. 133.
https://doi.org/10.1016/j.jbusres.2021.04.070

Etzkowitz, Henry; **Leydesdorff, Loet** (1996). "A triple helix of academic-industry-government relations: Development models beyond 'capitalism versus socialism'". *Current science*, v. 70, n. 8.

Etzkowitz, Henry; **Leydesdorff, Loet** (2000). "The dynamics of innovation: from National Systems and 'Mode 2' to a Triple Helix of university-industry-government relations". *Research policy*, v. 29, n. 2.
https://doi.org/10.1016/S0048-7333(99)00055-4

Kogler, Dieter-Franz; **Heimeriks, Gaston**; **Leydesdorff, Loet** (2018). "Patent portfolio analysis of cities: statistics and maps of technological inventiveness". *European planning studies*, v. 26, n. 11.
https://doi.org/10.1080/09654313.2018.1530147

Kostoff, Ronald N.; **Del-Río, J. Antonio**; **Cortés, Héctor D.**; **Smith, Charles**; **Smith, Andrew**; **Wagner, Caroline**; **Leydesdorff, Loet**; **Karypis, George**; **Malpohl, Guido**; **Tshiteya, Rene** (2007). "Clustering methodologies for identifying country core competencies". *Journal of information science*, v. 33, n. 1.
https://doi.org/10.1177/0165551506067124

Leydesdorff, Loet (1979). "*Dynamic and stochastic models for reciprocal citation processes*" (Thèse de doctorat, Université d'Amsterdam).

Leydesdorff, Loet (2007). "Betweenness centrality as an indicator of the interdisciplinarity of scientific journals". *Journal of the American Society for Information Science and Technology*, v. 58, n. 9.
https://doi.org/10.1002/asi.20614

Leydesdorff, Loet (2001). "*A sociological theory of communication; The self-organization of the knowledge-based Society*". Universal Publishers / upublish.com, USA.
https://www.universal-publishers.com/m/book.php?method=ISBN&book=1581126956

Leydesdorff, Loet (1987). "Various methods for the mapping of science". *Scientometrics*, v. 11, n. 5-6.
https://doi.org/10.1007/BF02279351

Leydesdorff, Loet (1997). "Why words and co-words cannot map the development of the sciences". *Journal of the American Society for Information Science*, v. 48, n. 5.

Leydesdorff, Loet (2004). "Clusters and maps of science journals based on bi-connected graphs in Journal Citation Reports". *Journal of documentation*, v. 60, n. 4.
https://doi.org/10.1108/00220410410548144

Leydesdorff, Loet (2007). "Mapping interdisciplinarity at the interfaces between the science citation index and the social science citation index". *Scientometrics*, v. 71, n. 3.
https://doi.org/10.1007/s11192-007-1694-z

Leydesdorff, Loet (2007). "Betweenness centrality as an indicator of the interdisciplinarity of scientific journals". *Journal of the American Society for Information Science and Technology*, v. 58, n. 9.
https://doi.org/10.1002/asi.20614

Leydesdorff, Loet (2011). "'Meaning' as a sociological concept: A review of the modeling, mapping and simulation of the communication of knowledge and meaning". *Social science information sur les sciences sociales*, v. 50, n. 3-4.
https://doi.org/10.1177/0539018411411021

Leydesdorff, Loet; **Bihui, Jin** (2004). "Mapping the Chinese science citation database". In: *University of Amsterdam*, v. 41.
https://doi.org/10.1002/meet.1450410157

Leydesdorff, Loet; **Bihui, Jin** (2005). "Mapping the Chinese Science Citation Database in terms of aggregated journal-journal citation relations". *Journal of the American Society for Information Science and Technology*, v. 56, n. 14.
https://doi.org/10.1002/asi.20209

Leydesdorff, Loet; **Bornmann, Lutz** (2012). "Mapping (USPTO) patent data using overlays to Google Maps". *Journal of the American Society for Information Science and Technology*, v. 63, n. 7.
https://doi.org/10.1002/asi.22666

Leydesdorff, Loet; **Cozzens, Susan**; **Van-den-Besselaar, Peter** (1994). "Tracking areas of strategic importance using scientometric journal mappings". *Research policy*, v. 23, n. 2.
https://doi.org/10.1016/0048-7333(94)90054-X

Leydesdorff, Loet; **De-Moya-Anegón, Félix**; **Guerrero-Bote, Vicente P.** (2010). "Journal maps on the basis of Scopus data: A comparison with the Journal Citation Reports of the ISI". *Journal of the American Society for Information Science and Technology*, v. 61, n. 2.
https://doi.org/10.1002/asi.21250

Leydesdorff, Loet; **De-Moya-Anegón, Félix**; **Guerrero-Bote, Vicente P.** (2015). "Journal maps, interactive overlays, and the measurement of interdisciplinarity on the basis of Scopus data (1996-2012)". *Journal of the Association for Information Science and Technology*, v. 66, n. 5.
https://doi.org/10.1002/asi.23243

Leydesdorff, Loet; **Heimeriks, Gaston**; **Rotolo, Daniele** (2016). "Journal portfolio analysis for countries, cities, and organizations: Maps and comparisons". *Journal of the Association for Information Science and Technology*, v. 67, n. 3.
https://doi.org/10.1002/asi.23551

Leydesdorff, Loet; **Kogler, Dieter-Franz**; **Yan, Bowen** (2017). "Mapping patent classifications: portfolio and statistical analysis, and the comparison of strengths and weaknesses". *Scientometrics*, v. 112, n. 3.
https://doi.org/10.1007/s11192-017-2449-0

Leydesdorff, Loet; **Meyer, Martin** (2010). "The decline of university patenting and the end of the Bayh-Dole effect". *Scientometrics*, v. 83, n. 2.
https://doi.org/10.1007/s11192-009-0001-6

Leydesdorff, Loet; **Persson, Olle** (2010). "Mapping the geography of science: Distribution patterns and networks of relations among cities and institutes". *Journal of the American Society for Information Science and Technology*, v. 61, n. 8.
https://doi.org/0.1002/asi.21347

Leydesdorff, Loet; **Ràfols, Ismael** (2009). "A global map of science based on the ISI Subject Categories". *Journal of the American Society for Information Science and Technology*, v. 60, n. 2.
https://doi.org/10.1002/asi.20967

Leydesdorff, Loet; **Salah, Alkim-Almila-Akdag** (2010). "Maps on the basis of the *Arts & Humanities Citation Index*: The journals *Leonardo* and *Art Journal* versus 'digital humanities' as a topic". *Journal of the American Society for Information Science and Technology*, v. 61, n. 4.
https://doi.org/10.1002/asi.21303

Leydesdorff, Loet; **Schank, Thomas** (2008). "Dynamic animations of journal maps: Indicators of structural changes and interdisciplinary developments". *Journal of the American Society for Information Science and Technology*, v. 59, n. 11.
https://doi.org/10.1002/asi.20891

Leydesdorff, Loet; **Wagner, Caroline S.**; **Bornmann, Lutz** (2018). "Betweenness and diversity in journal citation networks as measures of interdisciplinarity - A tribute to Eugene Garfield". *Scientometrics*, v. 114, n. 2.
https://doi.org/10.1007/s11192-017-2528-2

Leydesdorff, Loet; **Wagner, Caroline S.**; **Park, Han-Woo**; **Adams, Jonathan** (2013). "International collaboration in science: the global map and the network". *Profesional de la informacion*, v. 22, n. 1.
https://doi.org/10.3145/epi.2013.ene.12

Leydesdorff, Loet; **Welbers, Kasper** (2011). "The semantic mapping of words and co-words in contexts". *Journal of informetrics*, v. 5, n. 3.
https://doi.org/10.1016/j.joi.2011.01.008

Mingers, John; **Leydesdorff, Loet** (2015). "A review of theory and practice in scientometrics". *European journal of operational research*, v. 246, n. 1.
https://doi.org/10.1016/j.ejor.2015.04.002

Moral-Muñoz, José A.; **Herrera-Viedma, Enrique**; **Santisteban-Espejo, Antonio**; **Cobo, Manuel J.** (2020). "Software tools for conducting bibliometric analysis in science: An up-to-date review". *Profesional de la información*, v. 29, n. 1.
https://doi.org/10.3145/epi.2020.ene.03

Park, Han Woo; **Leydesdorff, Loet** (2008). "Korean journals in the Science Citation Index: What do they reveal about the intellectual structure of S&T in Korea?". *Scientometrics*, v. 75, n. 3.
https://doi.org/10.1007/s11192-007-1862-1

Park, Han Woo; **Leydesdorff, Loet** (2009). "Knowledge linkage structures in communication studies using citation analysis among communication journals". *Scientometrics*, v. 81, n. 1.
https://doi.org/10.1007/s11192-009-2119-y

Perret, Arthur; **Brioudes, Guillaume**; **Borel, Clément**; **Le Deuff, Olivier** (2023). *Cosma* (2.2.1).
https://doi.org/10.5281/zenodo.5412314
https://cosma.arthurperret.fr

Ràfols, Ismael; **Porter, Alan L.**; **Leydesdorff, Loet** (2010). "Science overlay maps: A new tool for research policy and library management". *Journal of the American Society for Information Science and Technology*, v. 61, n. 9.
https://doi.org/10.1002/asi.21368

Van-den-Besselaar, Peter; **Leydesdorff, Loet** (1996). "Mapping change in scientific specialties: A scientometric reconstruction of the development of artificial intelligence". *Journal of the American Society for Information Science*, v. 47, n. 6.
https://doi.org/10.1002/(SICI)1097-4571(199606)47:6<415::AID-ASI3>3.0.CO;2-Y

Wagner, Caroline S.; **Leydesdorff, Loet** (2005). "Network structure, self-organization, and the growth of international collaboration in science". *Research policy*, v. 34, n. 10.
https://doi.org/10.1016/j.respol.2005.08.002

Zupic, Ivan; **Čater, Tomaž** (2015). "Bibliometric methods in management and organization".
https://journals.sagepub.com/doi/10.1177/1094428114562629