Science overlay maps: A tribute to Loet Leydesdorff

Benjamín Vargas-Quesada; Wenceslao Arroyo-Machado; Teresa Muñoz-Écija; Zaida Chinchilla-Rodríguez

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Benjamín Vargas-Quesada
https://orcid.org/0000-0001-5115-7460

Universidad de Granada
Unit for Computational Humanities and Social Sciences (*U-CHASS*)
Colegio Máximo de Cartuja
18071 Granada, Spain
benjamin@ugr.es

Wenceslao Arroyo-Machado ✉
https://orcid.org/0000-0001-9437-8757

Universidad de Granada
Unit for Computational Humanities and Social Sciences (*U-CHASS*)
Colegio Máximo de Cartuja
18071 Granada, Spain
wences@ugr.es

Teresa Muñoz-Écija
https://orcid.org/0000-0003-1311-0471

Independent researcher.
Granada, Spain
teresamunyozecija@gmail.com

Zaida Chinchilla-Rodríguez
https://orcid.org/0000-0002-1608-4478

Consejo Superior de Investigaciones Científicas (*CSIC*)
Instituto de Políticas y Bienes Públicos (*IPP*)
Albasanz, 26-28
28037 Madrid, Spain
zaida.chinchilla@csic.es

Abstract

This is a homage to Loet Leydesdorff, professor and leading scientist.. Through the combination of overlay maps, a visualization technique proposed by himself and Ismael Ràfols, together with the CAMEOs (Characterizations Automatically Made and Edited Online) proposed by Howard White, we project his scientific trajectory in five different scenarios, which turn out to be complementary. For each of the scenarios or CAMEOs, we show how he acts and interacts from the point of view of scientific research, providing the reader with online access to an interactive *VOSviewer* tool, so that he can check the information presented here, and even go deeper into the analysis. In fact, we encourage him to do so. To sum up, we can say that Loet was a brilliant scientist, a lone wolf who enjoyed collaborating with the best minds in his main research topics: scientific communication, innovation systems, bibliometrics, and science mapping; becoming in turn the reference point of these areas of research.

Keywords

Loet Leydesdorff; Science mapping; Overlay maps; CAMEOs; Network analysis; *VOSviewer*; Bibliometrics; Scientific communication; Researchers.

1. Introduction

Loet (Louis André) Leydesdorff was a renowned professor and researcher at the *University of Amsterdam*. He passed away on March 11, 2023. He was noted for his pioneering research in innovation systems, scientific communications, scientometrics and science mapping, proposing an important improvement for the latter: overlay maps (**Leydesdorff**; **Ràfols**, 2009). Overlays are a very powerful contribution integrating visualization techniques, social networks, cognitive and intellectual structure, changes over time, and benchmarking analysis, for any kind of scientific domain. In fact, overlays demonstrated right away their great potential for research policy analysis and library management (**Ràfols** *et al.*, 2010), building interactive maps (**Leydesdorff**; **Ràfols**, 2012), charting patent data (**Leydesdorff**; **Bornmann**, 2012),

guesstimating interdisciplinarity (**Leydesdorff**; **Carley** *et al.*, 2013; **Leydesdorff**; **Ràfols** *et al.*, 2013), evaluating strategic intelligence in emerging technologies (**Rotolo** *et al.*, 2017), detecting and identifying emerging research fields (**Vargas-Quesada** *et al.*, 2017; **Muñoz-Écija** *et al.*, 2019), unveiling cognitive structures (**Muñoz-Écija** *et al.*, 2022), and comparing educational technologies (**Vargas-Quesada** *et al.*, 2021).

> "Overlays are a very powerful contribution integrating visualization techniques, social networks, cognitive and intellectual structure, changes over time, and benchmarking analysis, for any kind of scientific domain"

In this paper, we present a comprehensive homage to Loet Leydesdorff's remarkable career. Using scientific maps as a tool, we aim to synthesize the CAMEOs (Characterizations Automatically Made and Edited Online) proposed by **White** (2001) together with overlay maps –a technique Loet significantly contributed to. This approach enables us not only to reveal the various conceptual and social structures present in Loet's multifaceted research, but also to highlight the trends and visibility of his influential work across different domains. Thus, the specific objectives of this study are as follows:

1. To identify the primary research topics of Loet Leydesdorff's career, along with the trends and impacts throughout his professional journey.
2. To identify Loet Leydesdorff's main co-authors and his collaborative networks.
3. To analyze the researchers who have had an influence on Loet Leydesdorff's career, as well as those whom he has influenced.

2. Data and methods

2.1. Data

Data collection was conducted on April 27, 2023. We used *Clarivate*'s *Web of Science* (*WoS*) to search for all records of researchers with the surname "Leydesdorff" and whose first initial was "L." Two valid profiles were found: the first was verified, encompassing all production indexed in *Web of Science* (ResearcherID: E-2903-2010), and the second was unverified, with most of the production external to *Web of Science* (ResearcherID: DUT-0376-2022). We merged both profiles and downloaded all bibliographic records indexed in the *Web of Science Core Collection* in a tab-delimited file. In total, 427 bibliographic records were downloaded, representing the total research output of Loet Leydesdorff, with no documentary or temporal filtering applied.

2.2. Methods

The analysis carried out is mainly based on the social network analysis for the construction of scientific maps. Specifically, we have generated the following maps:

1. The conceptual structure, composed of the main topics and areas of research in which he published during his career.
2. The co-authors, composed of his main collaborators.
3. The citation identity, composed of the authors cited by Loet Leydesdorff and therefore on which his research is founded.
4. The citation image-makers, composed of the authors who cite Loet Leydesdorff and therefore on whom he influences.

We used *VOSviewer* (**Van Eck**; **Waltman**, 2010) for the construction of science maps. The specific details and processes involved in their elaboration are comprehensively outlined in Table 1. For each map, we have developed different overlay versions based on these networks. The purpose of these overlays is to augment the existing information with additional layers, thereby enabling a more in-depth identification and analysis of research performance and trends. These overlays essentially act as lenses that bring into focus the multifaceted aspects of Loet's research impact, thus offering a more

Table 1. Summary of scientific maps created on the production of Loet Leydesdorff

Network	Level	Data processing	Network filters
Conceptual structure Co-occurrence network	Publication	**Data:** Loet's Leydesdorff publications **Processing:** term extraction from titles and abstracts and normalization through the creation of a thesaurus	- Binary counting - Minimum 5 occurrences
Co-author Co-author network	Author	**Data:** Loet's publications **Processing:** author disambiguation through the creation of a thesaurus	- Full counting - Minimum 2 collaborations
Citation identity Citation network	Author	**Data:** Loet's publications + cited references **Processing:** the Britton Chance bibliometric analysis (**Li** *et al.*, 2014) was removed to avoid introducing noise with its references	- Minimum 3 documents
Citation image-makers Citation network	Author	**Data:** publications citing Loet's oeuvre	- Minimum 5 documents

comprehensive view of his scholarly influence and trajectory. In the case of the word co-occurrence network, the overlay map includes ad hoc indicators processed from the publications. These are the average age of the publications and the percentage of publications as the first author. In both cases, the values are normalized to range between 0% and 100%. The rest of the indicators used in overlay maps are the default calculated ones: average publication year and average normalized citations.

> In Loet's production we can distinguish three periods: 1980-2004 (preliminary development); 2005-2013 (fast development); and 2014-2022 (downward development)

All CAMEOs are accessible for interactive viewing via *VOSviewer Online*. Accompanying each figure, a link is provided to this application, enabling the exploration of the different scenarios of Loet's research trajectory and its evolution, as well as the possibility of visualizing other bibliometric indicators such as average publication year and average normalized citations, which further broaden the analytical value of each of these CAMEOs. For each map, it is specified whether the overlay can be applied via color variables (item colors) or size (item size). These options, among others included in the tool, are selectable from the drop-down panel on the left.

Due to space limitations, we do not conduct a detailed/depth analysis of each CAMEO. However, we leave this to the reader, so that she/he can take advantage of the possibilities of the tool we put at his disposal and keep discovering Loet's characterization, –and who knows, maybe she/he will find himself on those maps.

3. Results

Loet's production runs from 1980 to 2022[1] (Figure 1). We can distinguish three periods: 1980-2004 (preliminary development); 2005-2013 (fast development); and 2014-2022 (downward development). A quarter of his production is characterized by single-authorship papers (26.53%; 113 out of 426), a low level of co-authorship (2.23), and high percentage of international collaborative publications (57.41%). The correlation coefficient between average number of authors and number of publications is 0.042. Those of us who knew him know that all this says a lot about Loet's way of being and working, and all this carries over to his CAMEOs.

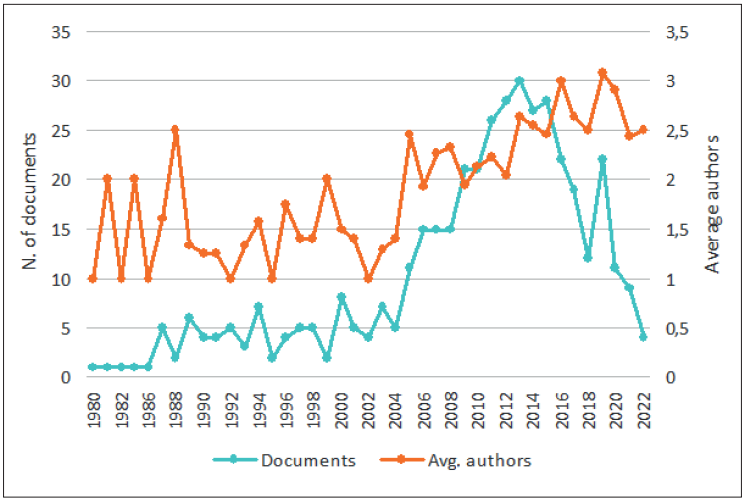

Figure 1. Loet Leydesdorff 's scientific production and co-authorship patterns.

3.1. Loet's conceptual structure

The conceptual structure, depicted through the most frequently co-occurring terms, outlines the primary areas and specific topics that Loet discusses most. With the aid of overlay maps, it is possible to discern main trends and assess the impact of these areas and topics more effectively.

Figure 2 presents the conceptual structure of research conducted by Loet. The thematic map (Figure 2a) highlights four main areas in which he has published: bibliometrics, innovation systems, science mapping, and scientific communication. This map displays a distinct division between areas focused on scientometrics and social network analysis (on the left) and areas focused on innovation systems theories and the sociology of innovation (on the right).

Within each of these topics, there exist certain topics that marked the initial trajectory of his research career, as depicted in Figure 2b. It underscores his unique contribution to the field of Communication Studies and Science and Technology Studies, with the triple helix model (**Etzkowitz**; **Leydesdorff**, 1995) (right), that aims to comprehend the relationships and collaboration between university-industry-government to understand the transformation of academic knowledge within the economy through innovation strategies. Similarly, terms with notable average age (e.g., map, graph, and citation network) stand out Loet's role as international scientific benchmark in science mapping, what enhanced the analysis and visualization of the structure and dynamics of his scientific activity (**Leydesdorff**, 1987; **Wagner**; **Leydesdorff**, 2005; **Leydesdorff**; **Ràfols**, 2009; **Ràfols** *et al.*, 2010). Other topics that have been figured from his beginnings are the design and use of indicators to predict, evaluate, and analyze scientific production, such as national performance in relation to the proportion of words in publications (**Leydesdorff**, 1990), the probabilistic entropy (**Leydesdorff**, 2003) or betweenness centrality (**Leydesdorff**, 2007a), as well as the use of various analysis units (e.g. citation) to set up citation analysis on citation-based indicators (**Amsterdamska**; **Leydesdorff**, 1989).

Connections between main topics on the left and the right are basically established through nodes titled indicator (upper-left part), network (middle part), and technology (upper-right part), all of them key and cross-cutting topics throughout Loet Leydesdorff's research career. For instance, technology is linked to the innovation systems in the upper-right of the

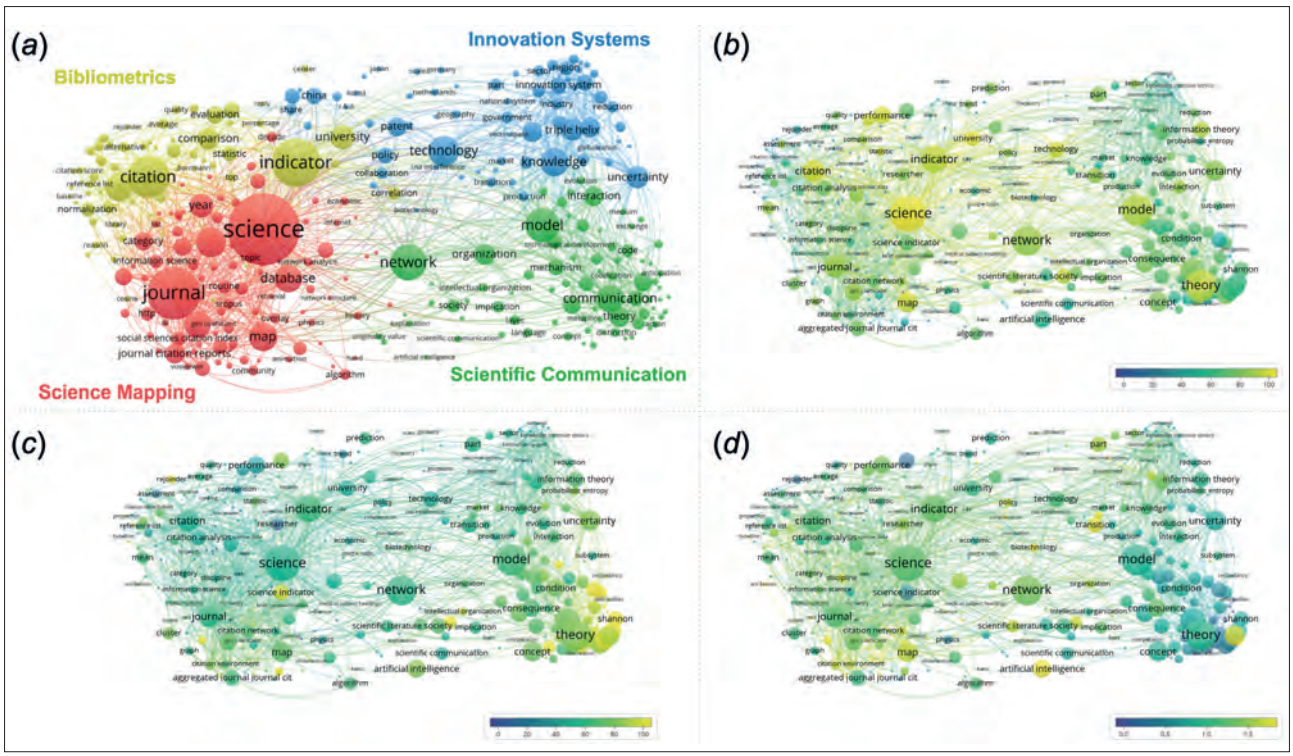

Figure 2. Loet Leydesdorff conceptual structure: (a) thematic landscape base map; (b) average age of the publications; (c) percentage of publications as the first author; (d) average normalized citations.
Visualizations available at *https://tinyurl.com/292roq5d*
Overlay map by colors (item colors -customizable at the left panel of the tool.

map, continuing with research in indicators to measure science and technology, in the upper-left part, using various methods and units –citation analysis and citation in the upper-left part; and map and journal in the lower-left part.

However, a crucial observation to make is that his performance and influence across these diverse areas does not display a consistent uniformity. Differences become evident when examining papers where he serves as the first author, understood as a proxy of leadership (**Zhou**; **Leydesdorff**, 2006) (Figure 2c), with a predominant leading role in scientific communication (we refer to **Leydesdorff**, 1994a; 1994b; 2000; 2001; 2007b; 2010; 2013; 2016; 2020; 2021). Intriguingly, this area demonstrates the lowest scholarly impact (Figure 2d), in comparison with the remaining areas where his influence is more evenly distributed. This trend shows that research areas that are more focused on theories and dogmas, in particular scientific communication, have a lower scholarly impact compared to areas concentrated on empirical data-based research, such as innovation systems and science mapping.

Regarding Loet's research (Figure 3), there is no evidence of periods in which activity is focused solely on a single topic. From its inception, his research has been highly diversified. Only in the early years, specifically in the late 1990s and early 2000s, we do observe most of the production focused on scientific communication and innovation systems. However, this period also corresponds to a lower rate of production, which could potentially accentuate these differences. From 2005 onwards, coinciding with a surge in productivity, research topics are more diversified, covering subjects across all four main areas identified in Figure 2.

For instance, by the late 1980s, the most predominant research areas were bibliometrics (e.g., evaluation, citation, statistics, citation analysis, and university) and science mapping (e.g., science and map). Nevertheless, in 1989, terms from the area of scientific communication become much more leading (e.g., intellectual organization and co-word). The same fact happens in 1990 with the area of innovation systems (e.g., information theory and prediction).

In the first half of the 1990s, research in scientific communication (e.g., model, society, network, scientific knowledge) and innovation systems (e.g., uncertainty, information theory, policy, and emergence) gain strength. Additionally, the topics within the field of science mapping remain active, while some bibliometrics topics lose prominence. It is worth noting that it is during these years when several articles on the triple helix model are published.

In the second half of the 1990s, there is a clear deepening in the study of areas of scientific communication (e.g., model, network, society, communication, theory, co-word, technological development) and innovation systems (e.g., triple helix, collaboration, technology, innovation, market, state, knowledge, competition). The area of science mapping remains active, but certain terms gain more significance (e.g., algorithm, discipline, journal, aggregate journal-journal citation, scientometrics, and scientific literature).

> Terms with notable average age (e.g., map, graph, and citation network) stand out Loet's role as international scientific benchmark in science mapping

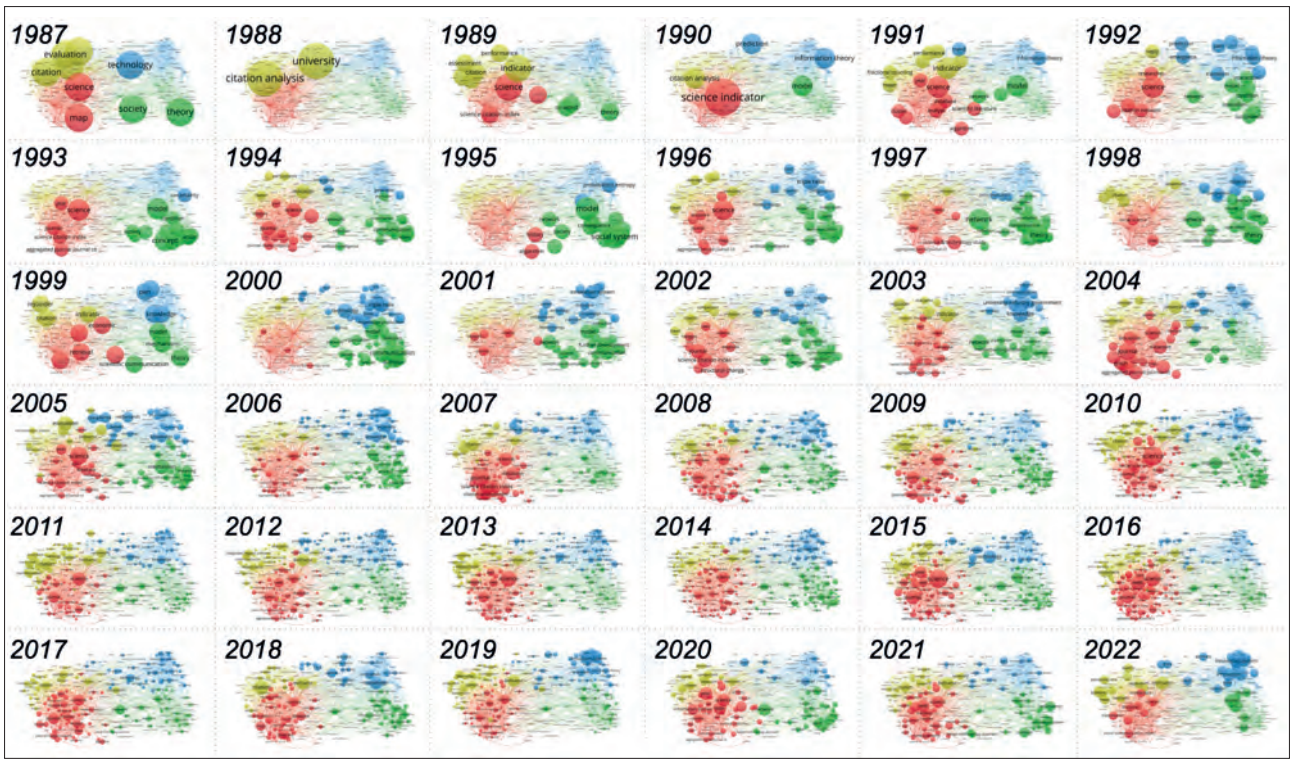

Figure 3. Overlay map of the annual evolution of Loet Leydesdorff topics between 1987 and 2022.
Visualizations available at https://tinyurl.com/24lnrkml
Overlay map by size (item size).

During the early 2000s, areas of bibliometrics, scientific communication, and innovation systems remain consistent. However, there is a notable increase in terms within the science mapping cluster between 2003 and 2004 (e.g., visualization, social network analysis, discipline, internet, cluster, classification, graph, and overlay). Moreover, in this period terms in central positions experience a growth, serving as a link between areas on the left and right (e.g., network, technology, and university).

Throughout the later years of the 2000s, the topics within science mapping continue increasing (e.g., web, journal, relation, research front, citation network, citation data, map, *Journal Citation Reports*, and *Scopus*). Bibliometrics also demonstrates an upward trend (university, indicator, citation, evaluation, normalization, ranking, and fractional counting), while the remaining areas remain stable.

Between 2011 and 2015, activity remains consistent in the four main areas. However, topics within the scientific communication field show reduced activity, while terms within bibliometrics (e.g., correlation, impact factor, and integrated impact indicator) and science mapping (e.g., animation, *VOSviewer*, subject area, overlay, interdisciplinarity) experience increased activity. This trend persists between 2016 and 2020, with a resurgence of activity in the scientific communication area (e.g., knowledge production, organization, subsystem, co-evolution) and heightened activity in certain innovation system topics (e.g., collaboration, international collaboration, patent, firm, and national system).

In the span of 2021 to 2022, the four research areas maintain their activity, with a homogeneous level of activity. It is evident that the diversification in Loet's productivity remains stable when his collaboration with other authors is high. The average collaboration indicator shows the highest values starting from 2016 when his scientific production experiences a decline.

3.2. Co-authors

Figure 4 shows Loet's social relationships, how he relates to one another, and how these co-authors can be grouped through clusters identifying groups and lines of research.

Loet publishes with 76 co-authors (Figure 4). The red cluster comprises 45 co-authors highlighting Lutz Bornmann as the most prolific partner (Figure 4a). Researchers participating in this cluster share a common research topic, scientometrics. The same pattern is observed for the two science mapping clusters, colored in blue and purple, with 9 and 6 authors. In particular, purple cluster focuses on the application of science mapping with *Scopus* dataset, as well as technical and

> Research areas that are more focused on theories and dogmas, in particular scientific communication, have a lower scholarly impact compared to areas concentrated on empirical data-based research, such as innovation systems and science mapping

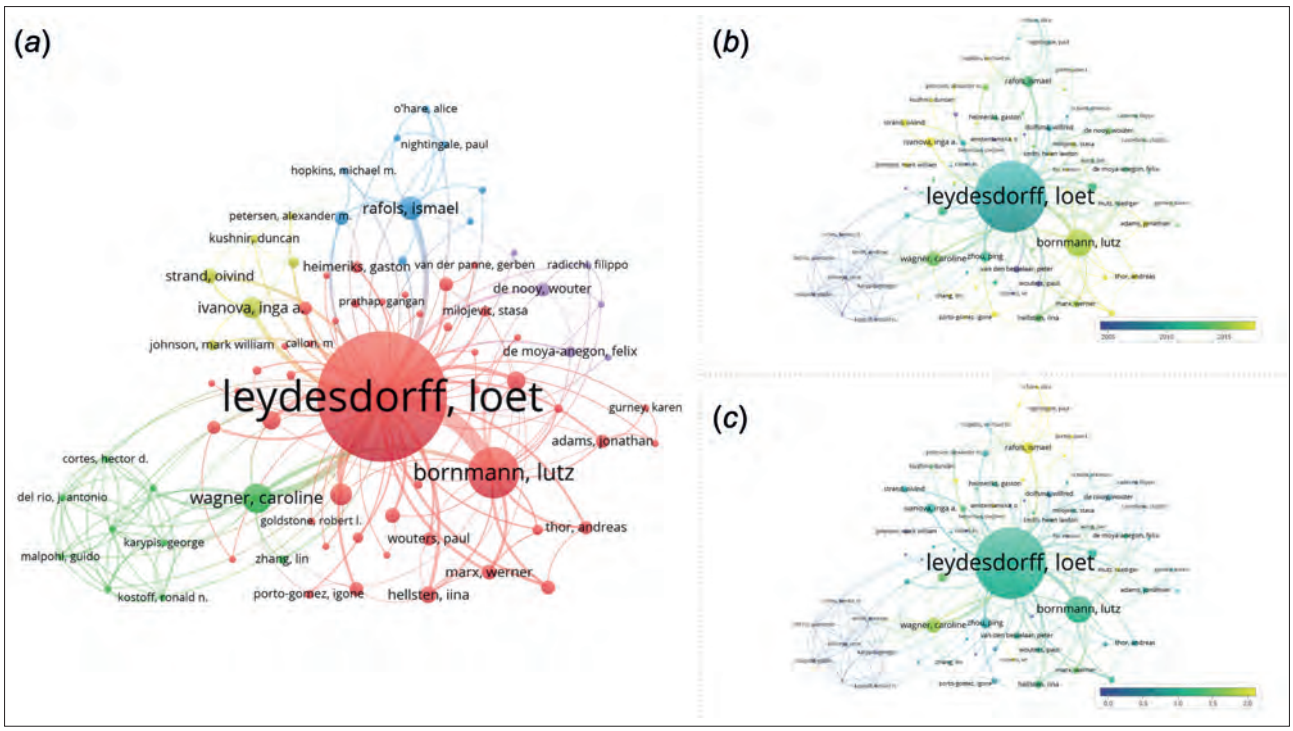

Figure 4. Focal Loet Leydesdorff co-authors: (a) co-author network base map; (b) average publication year; (c) average normalized citations.
Visualizations available at *https://tinyurl.com/29kc3yp4*
Overlay map by colors (item colors).

theoretical attributes of network analysis. Here, Ismael Ràfols and Wouter de Nooy emerge as principal contributors, respectively. Similarly, the green cluster is dominated by Caroline Wagner. The focal areas within this co-author group revolve around science policy and international collaboration. Lastly, the yellow cluster displays a reduced number of collaborators –only 6– who developed research in the area of the innovation systems.

When considering the average publication year, Lutz Bornmann is also a noteworthy figure (Figure 4b). Besides being the most prolific partner, his publications are also primarily concentrated in recent years. They published their first paper as co-author in 2007 (**Bornmann** *et al.*, 2007). Together they have published more than 75 publications in different areas of scientometrics such as field normalized indicator or network analysis. Inga Ivanova is another of the most active collaborators since 2014 (**Leydesdorff**; **Ivanova**, 2014) with 15 publications in the innovation systems, whose publication output continued up until 2021. As it is clearly visible, Caroline Wagner is also another of the top co-author (28 publications), presenting the distribution of publications enhanced stability over the years (2003-2022).

Nevertheless, it is worth noting the scholarly impact of publications carried out in conjunction with Ismael Ràfols (2.23) in the blue cluster, which have generated the greatest impact (ranged from 0.84 to 3.32), as depicted in Figure 4c. The same applies in the yellow cluster to Henry Etzkowitz, co-author alongside Loet of a few papers, which have achieved utmost average impact (2.56).

3.3. Loet's citation identity

The citation identity shows those from whom Loet consumes and uses scientific information, who are his reference points/benchmarks, to whom he pays tribute with his citations, and how they relate to each other.

The citation network of Loet Leydesdorff primarily revolves around three main areas, with two additional smaller communities that focus on more specific topics (Figure 5). The foremost area encompasses traditional studies of bibliometrics and citation analysis, represented by the red cluster. Here, we can be found leading authors in the field such as Ben R. Martin, Wolfgang Glänzel, and Ronald Rousseau. Closely associated with this is the green cluster, comprising the most recent studies in scientometrics. Notable authors in this area include Lutz Bornmann, Ludo Waltman, and Mike Thelwall. The third significant area involves network studies, represented by the blue cluster, where authors such as Ismael Ràfols, Alan Porter, and Kevin Boyack are prominent. It is upon the work of these authors that Loet's research is founded.

> Leydesdorff effect on leading scientists in the field of science and technology studies, in particular the scholarly communication, including Félix De-Moya-Anegón, Cassidy Sugimoto and Vincent Larivière is remarkable

Nonetheless, we cannot overlook the rest of clusters even though the sizes are considerably smaller. On the one hand, the scientific knowledge derived from the purple cluster has guided him in advancing research in international collaboration, public policy, identification

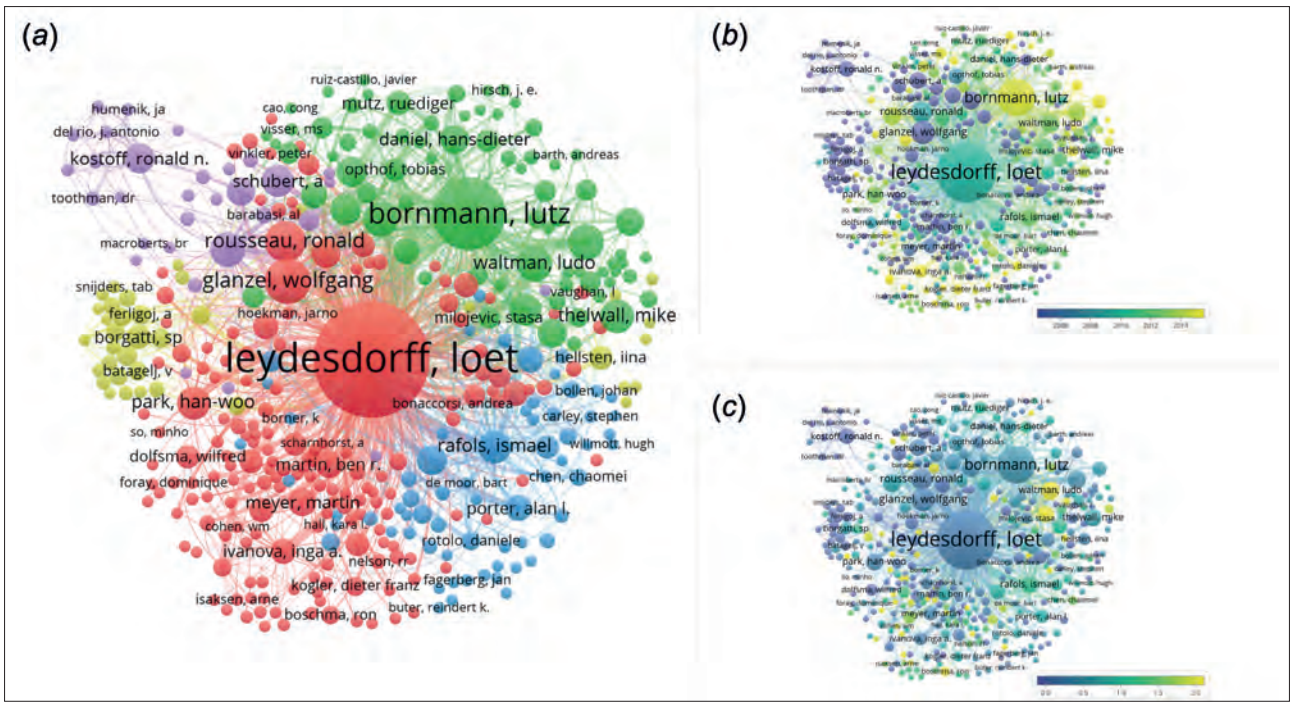

Figure 5. Loet Leydesdorff's citation identity: (a) citation network base map; (b) average publication year; (c) average normalized citations.
Visualizations available at *https://tinyurl.com/26uvs7kg*
Overlay map by colors (item colors).

of trends and delineation of research domains. Among these authors Caroline Wagner, András Schubert, and Ronald Kostoff stand out. On the other hand, authors in the yellow cluster have served as the sources of knowledge upon which Loet has relied for the development of research in social networks analysis and computational models. Prominent authors in these themes are Vladimir Batagelj, and Stephen Borgatti.

3.4. Loet's citation image-makers

This network shows just the opposite of the previous one. It reveals who consumes and uses the scientific information produced by Loet, how they relate and group themselves into invisible colleges.

In this case, the network of co-authors generated from the references of the publications citing Loet Leydesdorff (Figure 6) reflects similarities with respect to what was seen previously. The authors of bibliometrics and data analysis occupy a relevant space (red cluster), in which Loet Leydesdorff and Lutz Bornmann have a predominant presence. His effect on leading scientists in the field of science and technology studies, in particular the scholarly communication, including Félix De Moya Anegón, Cassidy Sugimoto and Vincent Lariviere (purple cluster, upper part) is also remarkable, holding central positions. Within the same cluster more focused on the scientific knowledge representation (lower part), renowned authors are displayed such as Ronald Rousseau, Wolfgang Glänzel, Ying Ding, Richard Klavans, and Kevin Boyack. The influence that Loet has in the field of technology policy assessment and emerging technology identification (blue cluster) is evident, with notable authors such as Alan Porter, Ismael Ràfols, Jan Youtie, and Philip Shapira standing out, among others. Likewise, his scientific endeavors have had a profound impact on development of indicators for analyzing knowledge-based innovation systems and scientific collaboration, as evidenced by the citations from Caroline Wagner, Han Woo Park, and Giovanni Abramo.

Lastly, there are two clusters with authors from other knowledge domains. The yellow cluster represents the influence on authors whose research careers are centered around Economy within Business Science, with a specific focus on entrepreneurship and innovation. The smaller one, the light blue cluster, comprises computer science researchers who study methods and techniques for analyzing and making decisions based on information and knowledge.

In terms of average normalized citations, researchers from the red cluster, along with those from the yellow and light blue clusters, exhibit the highest values (Figure 6c). By contrast, the average publication year of publications that cited Loet's output shows homogeneity among the various clusters comprising the network (Figure 6b). Sociology has been the pivotal axis of Loet's research, acting as a connecting bridge between his research on innovation systems and models and areas of scientometrics and social network analysis. This demonstrates the heterogeneity and transcendence/scope of the network, as Loet receives citations from diverse knowledge domains.

> Sociology has been the pivotal axis of Loet's research, acting as a connecting bridge between his research on innovation systems and models and areas of scientometrics and social network analysis

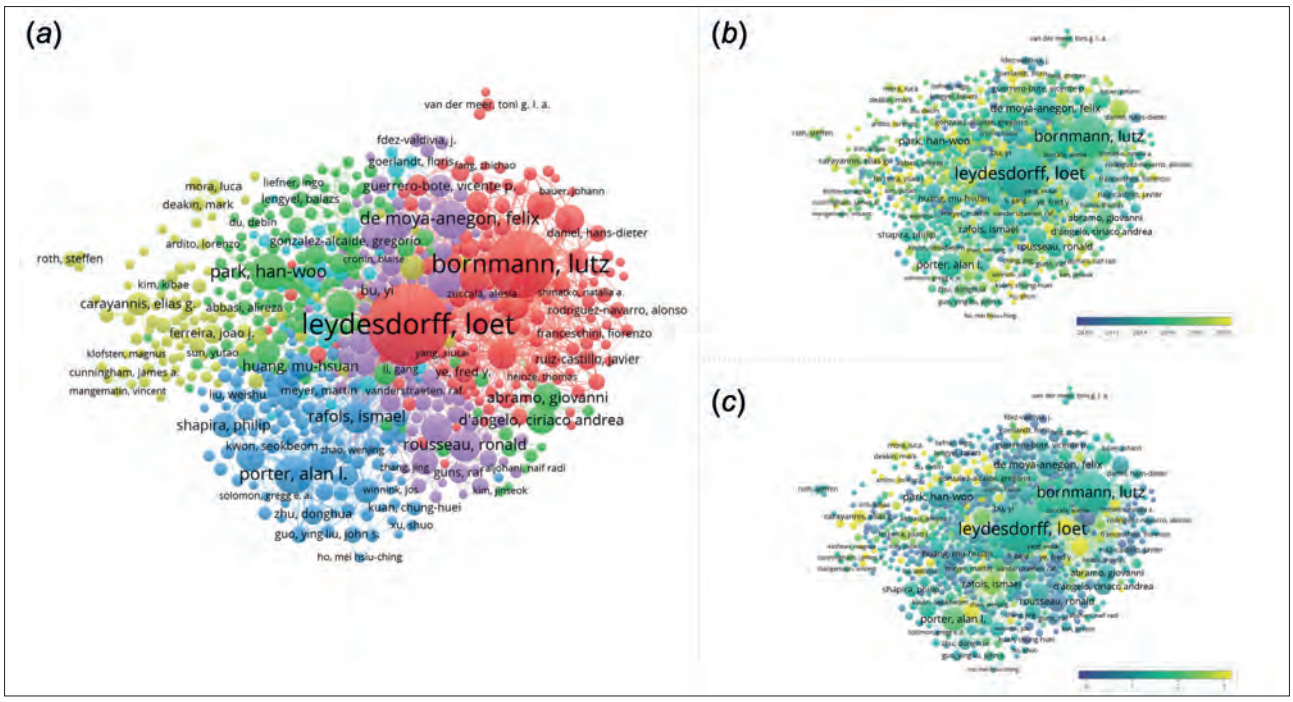

Figure 6. Loet Leydesdorff's citation image-makers: (a) citation network base map; (b) average publication year; (c) average normalized citations. Visualizations available at *https://tinyurl.com/28lzkco3*
Overlay map by colors (item colors).

Additionally, this emphasizes how his research encompasses multiple knowledge areas and how his cross-discipline intellectual perspectives exert significant influence within the scientific community.

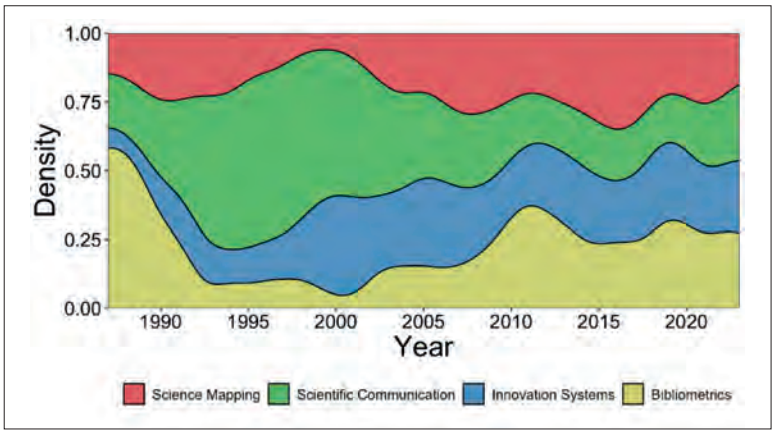

Figure 7. Annual evolution of topics published by Loet Leydesdorff by field

4. Limitations

We distinguish three different periods based on the identification of main research topics and the number of co-authors at international level as a starting point for analyzing Loet's oeuvre. Notwithstanding, none of the criteria selected allow us to determine these periods with exactitude. Indeed, we attempted to utilize the evolution of the topics on which Loet has published throughout his career. However, no distinct periods are discernible in his production based on this analysis (Figure 7). Other approaches could be applied in further research to explore the possibility of stablishing these periods in a more robust way (**Glänzel**; **Abdulhayoğlu**, 2018).

From a bibliometric perspective, a CAMEO allows us to see how a focal author, Loet in this case, performs in different scenarios. It is true that these CAMEOs are based on information extracted from *Web of Science*. Even if the number of publications does not significantly differ from those obtained in *Scopus* (three more documents), it is possible to enrich some CAMEOs using other sources such as *Dimensions*, *OpenAlex*, or *Google Scholar*. Nonetheless, depending on the data source used, CAMEOs based on citation would be greatly different, reduced, or even non-existent. On the other hand, we justify the absence of the CAMEO citation image because it is derived from the co-citation map based on Loet Leydesdorff as focal and the information provided coincides to a large extent with the co-authorship and citation maps.

5. Conclusions

This is a tribute to Loet Leydesdorff. Using overlay maps, a visualization technique developed by him, and CAMEOs, we show how he acts and interacts in different scenarios with science and its different actors.

Loet has always been a character. His research career has been characterized by a high number of solo papers, international collaboration, and thematic diversity. Only at the beginning, a greater focus on scientific communication and innovation systems is observed, but over time, as his productivity and scientific collaboration increases, his research topics diversify, encompassing four main subjects: scientific communication, innovation systems, bibliometrics, and science mapping.

From the point of view of scientific collaboration, Loet maintains strong rapport with his colleagues. Despite his great scientific productivity, he has distinguished himself by working alone and maintaining a small group of collaborators throughout his research life. Lutz Bornmann, Caroline Wagner, and Ismael Ràfols, the latter with whom he developed the overlay maps, stand out. The Citation Identity CAMEO reveals the authors from whom Loet draws inspiration for his research. In our field, particularly noteworthy are Ben R. Martin, Wolfgang Glänzel, and Ronald Rousseau, concerned with citation analysis; Lutz Bornmann, Ludo Waltman, and Mike Thelwall, with the most recent studies in scientometrics; and Ismael Ràfols, Alan Porter, and Kevin Boyack, with science mapping. Citation Image-Makers CAMEO shows the authors who consume Loet's scientific literature to generate new knowledge. Curiously, although this CAMEO would be the antagonist of the previous one, its results are very similar. In other words, the authors who are inspired by Loet and use him as a benchmark in their research are the same ones he turns to for reference points.. We can state that there is a very strong feedback process between his co-authors, those he cites and those who cite him, highlighting again Lutz Bornmann, Caroline Wagner, Alan Porter, and Ismael Ràfols.

> "Over time, as Leydesdorff's productivity and scientific collaboration increases, his research topics diversify, encompassing four main subjects: scientific communication, innovation systems, bibliometrics, and science mapping"

In the coming years, when we attend a congress or a bibliometric meeting, we will miss that at the end of any communication, the Chairman says: answers, questions... Loet?

Sit tibi terra levis, Loet.

6. Note

The only article from 2023, which is a letter authored by the *Distinguished Reviewers Board of Scientometrics*, has been omitted as it distorts the production picture for that year (**Abramo** *et al.*, 2023).

7. References

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