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Public–Private Partnership (PPP) in Road Infrastructure Projects: A Review of Evolution, Approaches, and Prospects

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Abstract: Public–private partnerships (PPPs) are a widely used procurement method for constructing, maintaining, and operating roads, constituting an alternative to the traditional public works model (TPW). This is because the efficiency of the PPP model has been highlighted over the TPW model. This study carried out a bibliometric analysis of 734 public articles from Scopus on PPPs in road infrastructure projects between 1993 and 2022. The results allow us to identify the general characteristics of the research; the most relevant articles; the most productive journals; and the most prolific authors, institutions, and countries and their main international cooperation networks, as well as to detect the main current research topics, which are: financial management, costs and pricing systems, privatization of transport infrastructure services, and sustainability. Consequently, this study provides a comprehensive overview of research on PPPs in road infrastructure projects over the last 30 years. This can reinforce and complement previous bibliometric analyses on PPPs in road infrastructure projects.

Keywords: public–private partnerships; highways; bibliometric analysis; funding

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1. Introduction

Road infrastructure is an essential component of economic development and societal connectivity. Public–private partnerships (PPPs) are a promising approach to raising private finance for road construction and maintenance. PPPs are contracts that last for a long time between the public and private sectors to provide public services and infrastructure and include sectors like transportation, energy, environment, health, security, and education [1–4]. In many countries, PPPs are becoming an increasingly popular way of procuring infrastructure and public services, as they allow governments to secure infrastructure without raising taxes or going into immediate debt [5]. The public sector encourages the private sector to get involved in infrastructure projects in developing or developed countries. The objective is to reduce the gap between the growing demand for road infrastructure and budgetary constraints and the ineffectiveness and inefficiency of traditional public procurement to address this road infrastructure deficit [6,7]. The adoption of PPPs has attracted increasing research interest in recent decades. This has translated into a remarkable increase in the volume of articles published and the variety of topics addressed, fields of study, and methodological approaches employed.

There are multiple studies in the previous literature on PPPs in infrastructure projects [8–17], so some authors argue that they tend to lack a holistic and integrative vision [18], so this research carries out a global review of PPPs in road infrastructure projects over the last 30 years, the objective of this research being to analyze the evolution of the scientific production of PPPs in road infrastructure projects, to highlight the main

advances during the period from 1993 to 2022. It highlights the most significant advances in research in this field during this period, identifies themes and trends of study, and points out the gaps in existing knowledge. Accordingly, the following research questions are posed:

Q1. What are the main characteristics of the research line?
Q2. What are the most influential publications?
Q3. Who are the most prolific contributors (journals, institutions, and countries)?
Q4. What is the trend in cooperation (journals, institutions, and countries)?
Q5. What are the main research topics and trends?

The present research is structured as follows: Section 2 presents the methodology, data source, and exclusion criteria of the analyzed documents, while Section 3 shows the main results that provide answers and evidence to the research questions posed (Q1 and Q2). Section 4 presents the top collaborators (Q3) and the trends in collaboration (Q4) across journals, institutions, and countries. Section 5 presents the main research topics and trends in PPPs in the road sector (Q5). In Section 6, you can find the main research findings, conclusions, limitations, and future lines of research.

2. Materials and Methods

2.1. Methodology Used for Analyzing Data

This study utilizes bibliometrics as a basis for its approach, which aims to identify, organize, retrieve, and evaluate research documents to examine the temporal evolution of a specific field [19–21]. Therefore, this methodology provides a comprehensive and systematic overview of the literature [22,23] to analyze the line of research, determining the fundamental issues, the most relevant and current methodologies, as well as the level of interest in the subject matter [24]. Consequently, in this study, we identify and analyze the fundamental elements of the interrelationship within the concepts of PPP and roads, presenting the metadata and trends found in diverse databases that address this specific field [21]. Additionally, network maps have been created and proposed using VOSviewer v.1.16.7 software to cluster and analyze related words.

In addition, we have created and proposed network maps using the VOSviewer program v.1.16.7 to organize and analyze related words. This software, being able to generate maps based on network data, facilitates the visualization and exploration of these maps. Additionally, VOSviewer can extrapolate and create networks encompassing publications, journals, countries, keywords, and research trends. Articles in these networks can be linked through co-authorship, co-occurrence, citations, bibliographic coupling, or co-citation links [25,26]. Van Eck and Waltman (2010) argue that the added value of this software lies in its ability to gather data from different scientific databases such as Web of Science, Scopus, Dimensions, and PubMed, as well as reference manager files like RIS EndNote and RefWorks [27].

2.2. Bibliometric Analysis Procedure

Three stages were used to apply the methodology, as depicted in Figure 1.

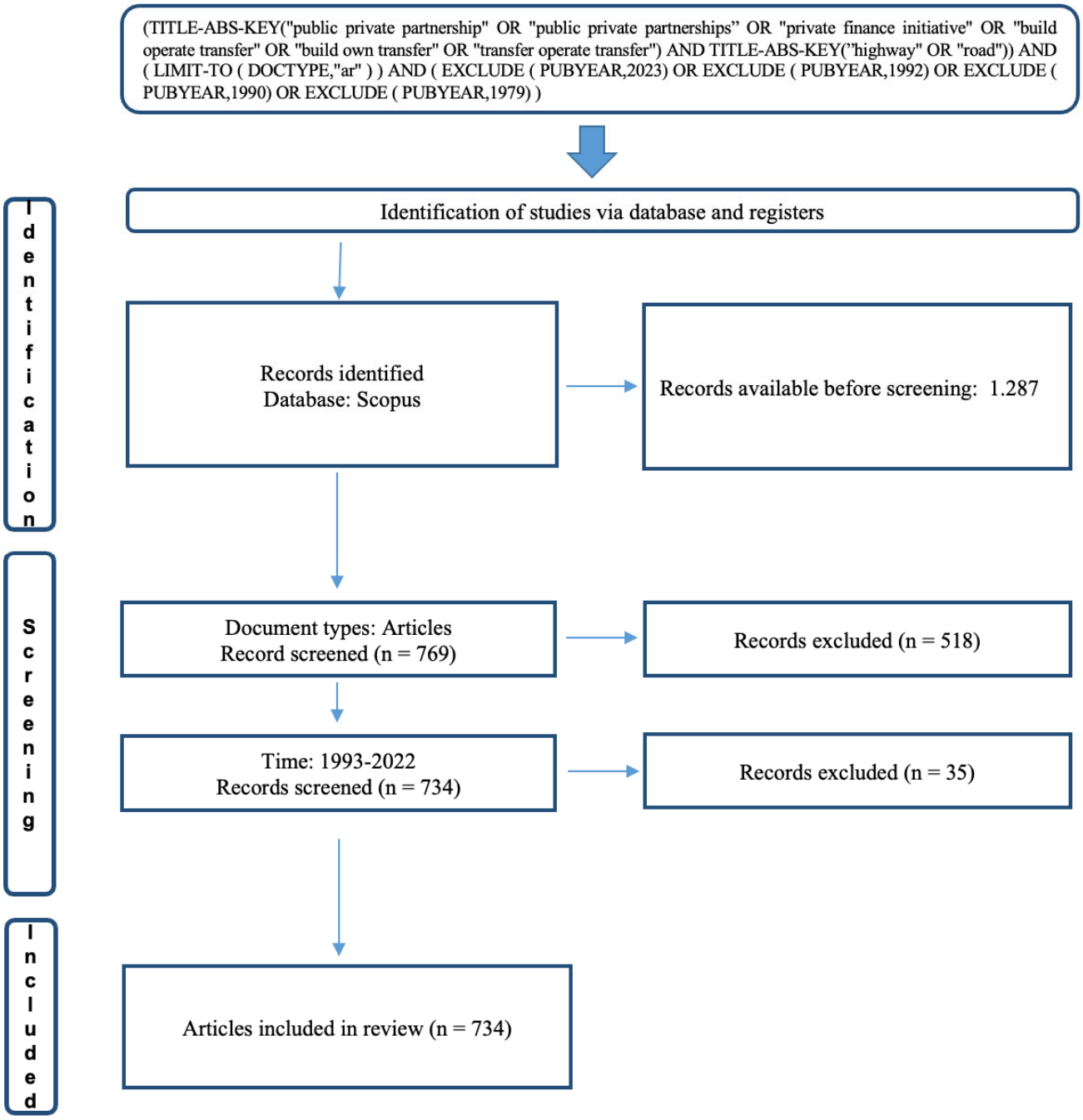

Figure 1. Methodology used.

Below is the methodological procedure used.

2.2.1. Identification Phase

We conducted an exhaustive review of the central databases, such as Google Scholar, PubMed, and Web of Science. Finally, we chose to use Elsevier's Scopus as the search engine, adhering to the suggestions of Harzing and Alakangas (2016) and Mongeon and Paul-Hus (2016) [28,29]. The rationale is that (a) it is the scientific repository that provides the most information on authors, institutions, and countries [30]; (b) it has a lot of articles and journals that meet scientific quality requirements [31]; and (c) in comparison with the Web of Science, it offers a broader coverage [32]. Given its recognized suitability for bibliometric reviews, several authors have considered Scopus to be the most appropriate scientific database [33].

A total of 1287 research papers meeting the search criteria were found. However, only some of these documents were considered for the analysis; different inclusion/exclusion criteria were applied to complete the research objective. The first criterion consisted of the type of paper that is scientific, where only research articles were selected. This is because novelty and exhaustive peer review are valued, indicating higher scientific quality [34,35]. Of the 1287 papers analyzed, only 769 met this search criterion. In addition, a time horizon covering research articles published between 1993 and 2022 was established, and as a result, 734 research articles that fulfilled the search criteria were retrieved.

The data were extracted on 23 May 2023. The search string used is as follows: (TITLE-ABS-KEY("public-private partnership" OR "public-private partnerships" OR "private finance initiative" OR "build operate transfer" OR "build own transfer" OR "transfer operate transfer") AND ("Highway" OR "road")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (EXCLUDE (PUBYEAR,2023) OR EXCLUDE (PUBYEAR,1992) OR EXCLUDE (PUBYEAR,1990) OR EXCLUDE (PUBYEAR,1979)).

2.2.2. Analysis and Visualization Phase

The data was downloaded and analyzed on 23 May 2023. From the sample that meets the search requirements, interactions between authors, countries, and institutions are examined, as well as the development of keywords. International cooperative networks are crucial in creating novel and high-impact research, as well as fostering the creation of synergies and the sharing of ideas [36,37]. This analysis is carried out using the co-citation method, i.e., as the frequency increases, the interrelationships between them also increase, resulting in a more excellent conceptual relationship.

The keyword analysis is based on the co-occurrence method, which identifies a conceptual and thematic structure. Thus, the results present an overview of the most prominent research areas related to road PPP. Table 1 shows the specific methods used to carry out the bibliometric analysis.

Table 1. Methods used in the bibliometric analysis.

Technique	Research Questions	Metrics	Analysis
Evaluation: Microsoft Excel v.16.81.	What are the main characteristics of the line of research?	Performance and impact.	Historical evolution of the leading indicators of scientific production.
	Which are the most influential publications?		Analysis of the most cited papers in the line of research.
	Who are the most prolific contributors (journals, authors, institutions, and countries)?		Distribution of published documents.
Relational: VOSviewer v.1.6.19.	What is the trend in cooperation (journals, institutions, and countries)?	Co-citation.	Analysis of co-citation between authors, institutions, and countries.
	What are the main research topics and trends?	Co-occurrence.	Keyword co-occurrence analysis.

2.2.3. Results Stage and Discussion

The results are presented in terms of authors, journals, subject areas, countries, affiliations, and international cooperation networks. Maps are also created based on the co-occurrence of keywords and co-citations, commonly utilized in bibliometric studies. These maps provide a meaningful visualization of relationships and trends within the study area, e.g., studies by Castelblanco et al. (2021) and Van Eck and Waltman (2010) [27,38].

3. The Main Characteristics of Scientific Production and the Most Influential Publications (Q1 and Q2)

The main features of scientific production in the research line on PPPs in road infrastructure projects from 1993 to 2022 are presented in this section. The next are the results related to the growing number of published articles; the number of authors, institutions, and countries published in the row of research; the total number of citations and the average number of citations received; and the number of journals in which the papers have been published, fitting the average number of authors for each published article without any filtering [39].

Callon et al. (1986) argue that the number of publications in a specific period can measure research activity [40]. The evaluation of indicators allows us to understand the quantitative evolution and research topic's structure [41]. The total period of 30 years has been subdivided into six subperiods of 5 years each (Table 2).

Table 2. Main characteristics of scientific production.

Year	Articles	Authors	Institutions	Countries	Journals	TC	TC/A	AU/A
1993–1997	27	39	21	8	19	134	4.96	1.4
1998–2002	36	74	54	13	27	579	16.08	2.1
2003–2007	49	79	54	19	36	1123	22.92	1.6
2008–2012	133	270	209	37	86	2444	18.38	2.0
2013–2017	212	465	369	48	137	4179	19.71	2.2
2018–2022	277	676	566	67	158	1450	5.23	2.4
1993–2022	734	1.603	1.273	192	341	9.909	13.50	2.0

(TC): total citations received; (TC/A) average total citations received; (AU/A): average number of authors per published paper.

Since the publication of the first research article entitled "Development of a freeway traffic management project through a public-private partnership", which analyzed the progress of a highway traffic management project across PPPs [42], all the indicators analyzed show exponential growth as a whole over the 30 years of development of the line of research. The comparison between the first subperiod (1993–1997) and the last one (2018–2022) reveals an increase of 925% in research articles, more than 1633% in authors and institutions participating in the line of research, 737% in countries, 731% in journals, and 982% in citations received.

Figure 2 represents the five-year evolution of the publications carried out in the field of research. It appears that there are two clearly differentiated periods: (a) the first period, from 1993 to 2007, shows a linear increase in the number of publications, indicating that the research topic is beginning to generate interest in the research community. The duration of this period saw the publication of 112 articles, thus laying the theoretical and conceptual foundations of the research line. (b) In the second period, from 2008 to 2022, exponential growth is evidenced, with the publication of up to 662 research papers.

During this second period, many authors, institutions, countries, and journals joined the line of research (Table 2). This growth could be explained by the global financial crisis of 2008 when the PPP market in the road sector experienced a slowdown. However, in Latin America, an immediate recovery was observed, unlike in the European Union, where the PPP market in the road sector took longer to recover [43]. This fact entailed a growing interest among researchers at the international level, so the global financial crisis posed a challenge in the research line to find more modern formulas to suit the new framework for action.

Table 3 shows the 24 thematic areas in which the 734 research articles on PPP in road infrastructure projects were classified. It is relevant to remember that the sum of the articles published by each research area is more significant than the total number of articles published since a paper may simultaneously belong to one or more research areas. The main research areas in which the topic has been posted are Engineering; Social

Sciences; and Business, Management and Accounting, representing 69.92% of the total scientific production.

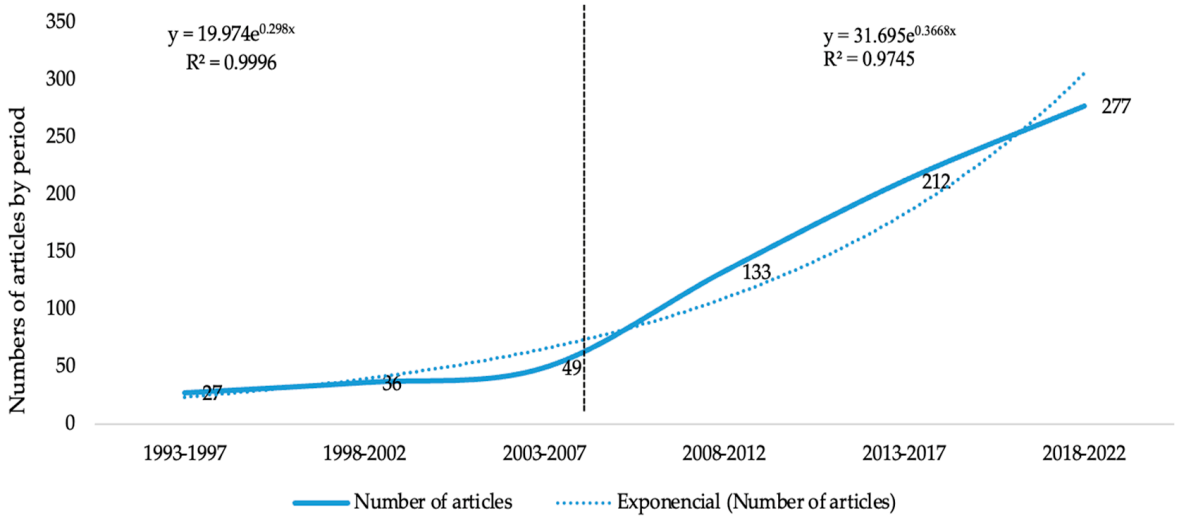

Figure 2. Number of papers published in each subperiod. Research trend.

Table 3. Area of research.

Area of Research	Total Publications	%
Engineering	384	29.31%
Social Sciences	308	23.51%
Business, Management and Accounting	224	17.10%
Economics, Econometrics and Finance	91	6.95%
Decision Sciences	68	5.19%
Environmental Science	65	4.96%
Computer Science	44	3.36%
Medicine	18	1.37%
Earth and Planetary	17	1.30%
Energy	17	1.30%
Mathematics	17	1.30%
Agricultural and Biological Sciences	12	0.92%
Materials Science	10	0.76%
Biochemistry, Genetics and Molecular Biology	7	0.53%
Multidisciplinary	5	0.38%
Arts and Humanities	4	0.31%
Chemistry	4	0.31%
Chemical Engineering	3	0.23%
Psychology	3	0.23%
Neuroscience	2	0.15%
Nursing	2	0.15%
Pharmacology, Toxicology and Pharmaceutics	2	0.15%
Physics and Astronomy	2	0.15%
Immunology and Microbiology	1	0.08%

It is interesting to analyze the evolution of each subject area over different periods: the first from 1993 to 2007 and the second from 2008 to 2022 (Figure 3). Notably, the trend has remained constant throughout both subperiods, with Engineering and Social Sciences remaining the main subject areas. However, Engineering has lost importance in favor of other areas such as Business, Management and Accounting and Economics, Econometrics and Finance. In particular, the area of Engineering received the most attention during the first period (n = 75; 41.44%). However, in the second period, this area experienced a decrease in attention (n = 309; 27.39%). Social Sciences showed its relevance in the first period (n = 43; 23.76%) and remained constant in the second period (n = 265; 23.49%).

Business, Management and Accounting showed some interest in the first period (n = 23; 12.71%) but experienced exponential growth in the second (n = 200; 17.73%). Similarly, Economics, Econometrics and Finance were minimally represented in the first period (n = 2; 1.10%) but experienced substantial growth in the second (n = 89; 7.89%). Decision Sciences recorded (n = 8; 4.42%) in the first period and experienced significant growth in the second period (n = 60; 5.32%). Finally, Environmental Sciences went from (n = 8; 4.42%) in the first period to (n = 57; 5.05%) in the second period. In short, the six thematic areas mentioned in the first period represented 87.85% of the scientific production. In contrast, in the second period, they reached 86.88% of the scientific output, so despite the variations in the relative importance of each of them within the line of research, they are considered the most productive thematic areas in research on public–private partnerships in road infrastructure projects.

The analysis of the areas themes reveals that throughout the entire period under analysis, "Engineering" has been the main (29.31%), followed by "Social Sciences" (23.51%), "Business, Management and Accounting" (17.10%), and "Economics, Econometrics, and Finance" (6.95%), with these four thematic areas accounting for 76.87% of the total number of publications. During the first period, 1993–2007, the most studied areas were Engineering (41.44%); Social Sciences (23.76%); and Business, Management and Accounting (12.71%). However, it was observed that during the second period (2008–2022), the area of Engineering (27.39%) decreased its relevance. In contrast, "Social Sciences" maintained its significance in both periods, as did "Business, Management and Accounting" (17.73%), and "Economics, Econometrics and Finance" (7.89%) experienced an increase. In particular, "Economics, Econometrics and Finance" was the fourth area of knowledge that contributed most to the PPP road research area.

Table 4 presents the main feature of the most cited research articles in the knowledge area.

The main academic contributions are grouped around several axes. Xu et al. (2010) developed a model for evaluating risk for road PPP projects in China. They concluded that this model could help governments and private companies improve the management of this type of project [44]. Along the same lines, Abednego and Ogunlana (2006) examined the perception of appropriate allocation of risk in PPP toll road projects in Indonesia and concluded that good governance improves project performance by promoting proper risk allocation [45]. Similarly, Ng et al. (2012), through a questionnaire and interviews targeting PPP experts in Hong Kong, identified three critical elements for success in the early stages of PPP project implementation: the existence of sustainable demand, the alignment of the project with government objectives, and the presence of a robust private consortium [46].

Yang and Meng (2000) analyzed the selection and evaluation of a road project using the build–operate–transfer (BOT) scheme in equilibrium networks. They considered pricing options, road capacity, and the effects of the choice of investigating profit and welfare. Their findings are valuable because they allow private investors to intuitively understand profitability and benefits and identify the conditions that make BOT-type projects viable and profitable [47]. Thomas et al. (2006), using the Delphi method and the fuzzy fault tree, put forward a risk probability and impact assessment framework and concluded that delay in financial closure, traffic income, demand, and land procurement are the most critical risks in BOT road projects [48]. Similarly, Iyer and Sagheer (2010) identified 17 essential risks of highway projects under PPP in India using the interpretive structural modeling (ISM) method to analyze the hierarchical structure and interrelationship of risks. They found that financial closure risk, schedule risk, and cost overrun risk were dependent on other risks, while 14 risks were autonomous and had little impact on each other. Cost overruns and schedule risks were the most vulnerable [49].

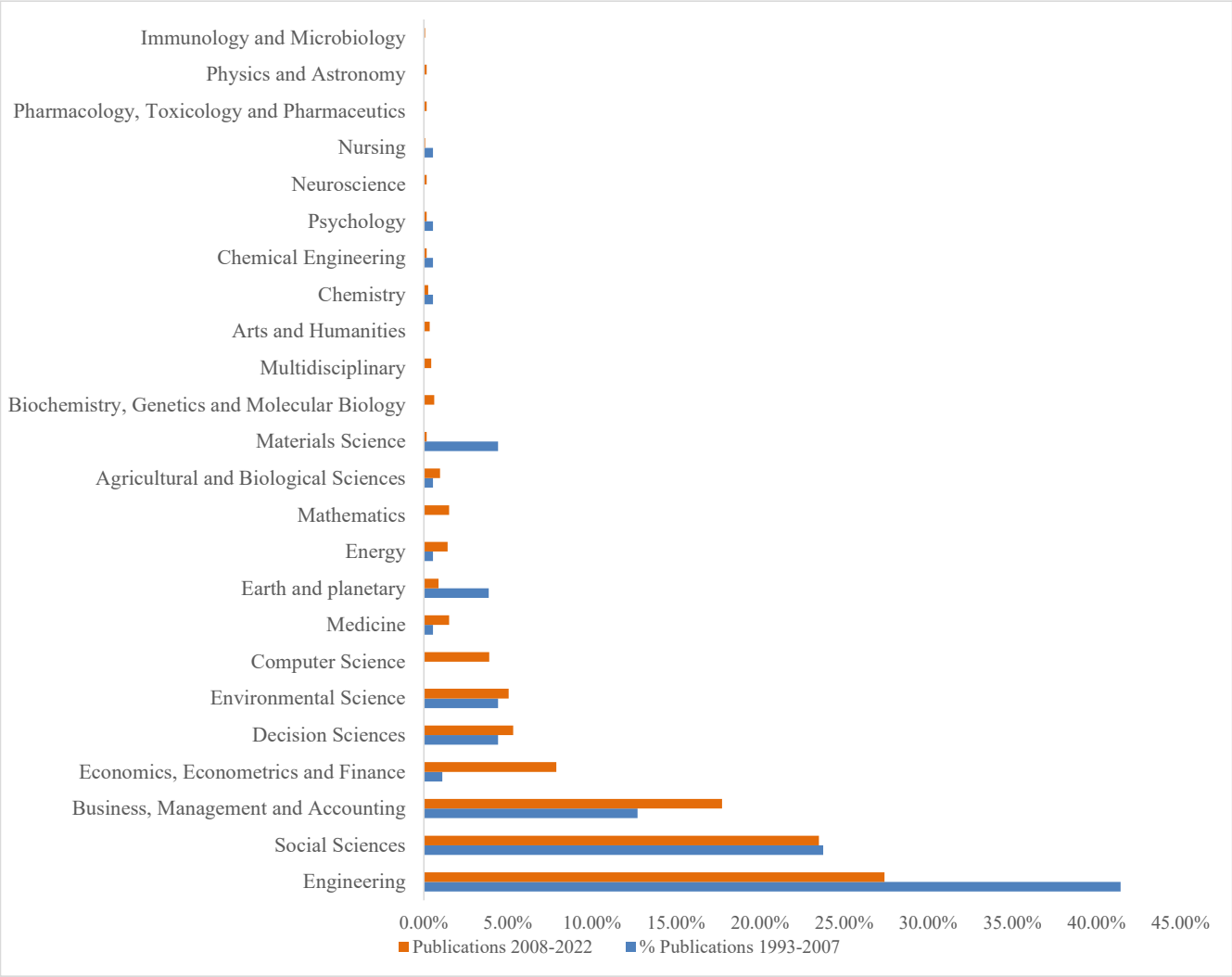

Figure 3. Evolution of the areas of research.

Table 4. Top 10 most cited research articles on PPPs in road infrastructure projects.

Authors	Year	Title	Cites
Xu et al.	2010	Developing a risk assessment model for PPP projects in China—A fuzzy synthetic evaluation approach	266
Abednego et al.	2006	Good project governance for proper risk allocation in public–private partnerships in Indonesia	230
Kivilä et al.	2017	Sustainable project management through project control in infrastructure projects	182
Rathi, S.	2006	Alternative approaches for better municipal solid waste management in Mumbai, India	164
Yang et al.	2000	Highway pricing and capacity choice in a road network under a build–operate–transfer scheme	163
Iyer and Sagheer	2010	Hierarchical structuring of PPP risks using interpretative structural modeling	156
Brandao et al.	2008	The option value of government guarantees in infrastructure projects	147
Ng et al.	2012	Factors influencing the success of PPP at feasibility stage—A tripartite comparison study in Hong Kong	137
Ashuri et al.	2012	Risk-neutral pricing approach for evaluating BOT highway projects with government minimum revenue guarantee options	132
Thomas et al.	2006	Modeling and assessment of critical risks in BOT road projects	128

Ashuri et al. (2012) determined the pricing of minimum revenue guarantee options on BOT projects using finance/decisional science theory. They found that the proposed model contributes to analyzing and understanding the financial risk of BOT projects [50].

Brandao and Saraiva (2008) used market data to estimate the stochastic parameters of the project, especially to evaluate a minimum traffic guarantee that grants the concessionaire a subsidy from the State if traffic is lower than expected [51]. On the other hand, Rathi (2006) compared community participation and participation by the private sector in waste management in Mumbai, India. Community participation costs USD 35 per ton due to waste separation, while PPP participation costs USD 41 per ton by focusing on waste processing [52]. Finally, Kivilä et al. (2017) analyzed the organization's control techniques to ensure sustainable project management. They found that sustainable project management results from a combination of indicators, control mechanisms, and sustainable project administration [53].

4. Partners and International Cooperation Networks (Q3 and Q4)

Below is a presentation of productivity results for authors, institutions, countries, and journals and their international cooperation networks. The 10 most productive authors in this research area are shown in Table 5.

It is worth mentioning that 40% of the authors are of Asian origin, followed by 30% from the USA. Likewise, 20% of the authors are from Europe, while only 10% are of Latin American origin. However, of the top 10 most productive authors, only the American Garvin, M.J. and the Colombian Guevara, J. worked together to write two co-authored research articles.

The Spanish author Vassallo, J.M. stands out as the most prolific author, with nine published research articles. He is followed by Guevara, J.; Wibowo, A.; and Yang, H. with eight published research articles. Chan, A.P.C. obtained the highest average number of citations per article, with an average of 89.80, followed by Yang, H., with an average of 62.38 citations per article, who also obtained the highest total citations (449).

On the other hand, the analysis through VOSviewer for international cooperation networks reveals that there is no international network in this line of research. Instead, co-authorships are mainly between researchers of the same nationality, indicating that this line of research is being addressed exclusively by authors from the same country (see Figure 4).

Table 5. Top 10 most productive authors.

Author	A	TC	TC/A	Institution	C	First A	Last A	H Index
Vassallo, J.M.	9	160	17.78	Polytechnic University of Madrid	Spain	2010	2021	6
Guevara J.	8	112	14.00	Universidad de Los Andes, Colombia	Colombia	2020	2022	7
Wibowo A.	8	145	18.13	Universitas Katolik Parahyangan	Indonesia	2005	2022	4
Yang, H.	8	499	62.38	Hong Kong University of Science and Technology	Hong Kong	2000	2017	8
DeCorla-Souza, P.	6	7	1.17	Federal Highway Administration	United States	2012	2020	2
Garvin, M.J.	6	177	29.50	Virginia Polytechnic Institute and State University	United States	2017	2020	6
Jha, K.N.	6	46	7.67	Indian Institute of Technology Delhi	India	2020	2021	4
Chan, A.P.C.	5	449	89.80	Hong Kong Polytechnic University	Hong Kong	2010	2018	5
Demirag, I.	5	118	23.60	Tallinna Tehnikaülikool	Estonia	2015	2021	5
Rouhani, O.M.	5	101	20.20	McGill University	Canada	2013	2018	5

A: number of published articles; TC: total citations; TC/A: mean number of citations per article; C: country; First A: first article published in the line of research; Last A: last article published in the line of research; H: Hirsch index in the line of research.

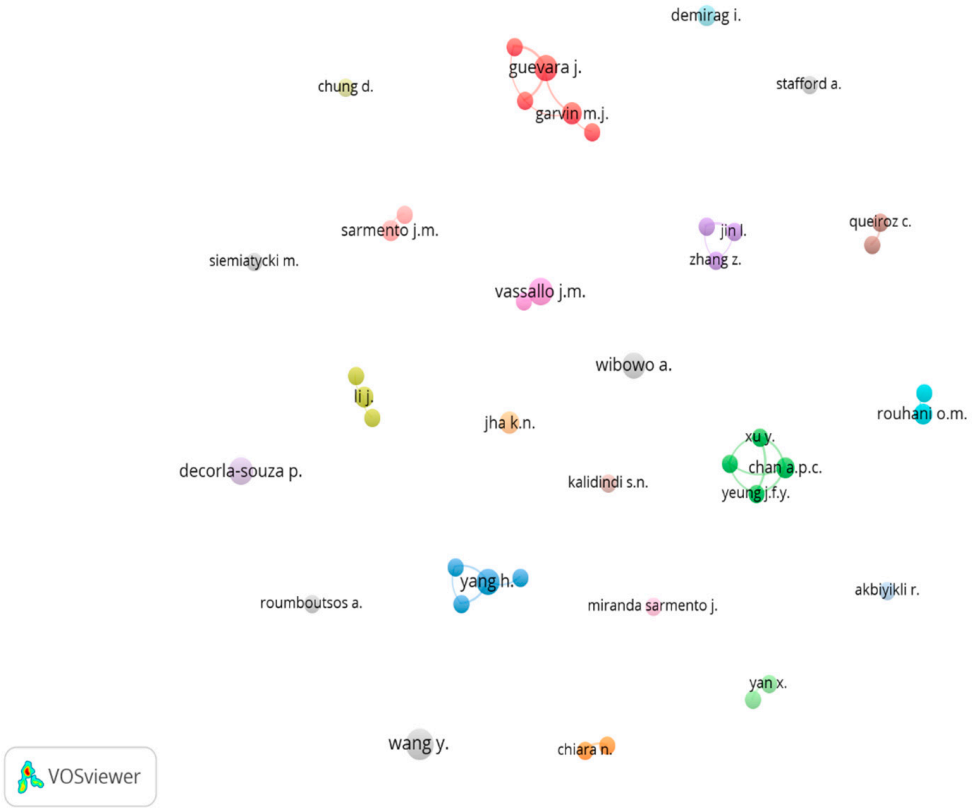

Figure 4. Authors' international cooperation networks on PPPs in road infrastructure projects.

Table 6 displays the top 10 institutions and their leading bibliometric indicators. The high concentration of institutions of Asian origin is noteworthy, representing 50% of the total, followed by institutions of North American and European heritage, each with 20% representation, and finally, institutions of Latin American origin with 10%. This broad international participation in the line of research is also evidenced by the fact that most of these institutions began publishing on the subject during the period of origin of the study (1993–2007), and all of them have continued to publish during the current period (2018–2022), indicating a high degree of interest in the scientific community. However, it is worth mentioning that international cooperation indexes have yet to be found.

The Universidad Politécnica de Madrid has the highest productivity, with 18 published research articles, although its H-index is the fifth highest (7). The Universidade de Lisboa follows it with 15 articles and an H-index of 3. The Hong Kong University of Science and Technology, the Hong Kong Polytechnic University, and the Universidad de Los Andes stand out with 10 research articles and H-indexes of 10, 8, and 6, respectively. The Hong Kong University of Science and Technology has obtained the highest dissemination of its research results, with 612 total citations and an average of 61.20. This gives it the highest standard among the top 10 most productive institutions. In second place is Hong Kong Polytechnic University, with 519 total citations and a mean of 51.90.

Figure 5 illustrates the international cooperation network of the institutions. An interplay of at least five research articles was selected, and 1256 institutions were found in total, of which only 56 were published in international cooperation networks on road PPPs, so it can be stated that collaborations are infrequent.

Table 7 displays the 10 most productive countries. The distribution of the countries in road PPP research is more diverse than that of authors and institutions. A total of 40% of the countries are of European origin, while 30% are of Asian origin. The remaining 20% is divided between North America and Oceania.

Table 6. Top 10 most productive institutions.

									TC/A	
Institution	**C**	**A**	**TC**	**TC/A**	**H Index**	**First A**	**Last A**	**IQ (%)**	**CI**	**NCI**
Polytechnic University of Madrid	Madrid	18	317	17.61	7	2010	2021	16.7%	1.33	20.87
University of Lisbon	Portugal	15	195	13.00	3	2011	2022	13.3%	7.00	13.92
Hong Kong University of Science and Technology	Hong Kong	10	612	61.20	10	2000	2017	70.0%	58.29	68.00
Hong Kong Polytechnic University	Hong Kong	10	519	51.90	8	2010	2022	90.0%	50.44	65.00
Universidad de Los Andes, Colombia	Colombia	10	116	11.60	6	2017	2022	70.0%	14.29	5.33
Dalian University of Technology	China	9	180	20.00	6	2014	2020	11.1%	20.00	20.00
Indian Institute of Technology Madras	India	9	358	39.78	8	2006	2021	33.3%	19.00	50.17
Indian Institute of Technology Delhi	India	9	241	26.78	4	2010	2021	11.1%	8.00	29.13
Federal Highway Administration	United States	8	30	3.75	2	2006	2020	0.0%	0.00	3.75
Cornell University	United States	8	216	27.00	3	1996	2019	62.5%	27.00	27.00

(C): country; (TC): total citations received; (TC/A) average total citations received; (H index) Hirsch index in the line of research; (First A): first article published in the line of research; (Last A): last article published in the line of research; (CI) cooperation index; (TC/A CI): average citations in international cooperation; (TC/A NCI): average citations without international cooperation.

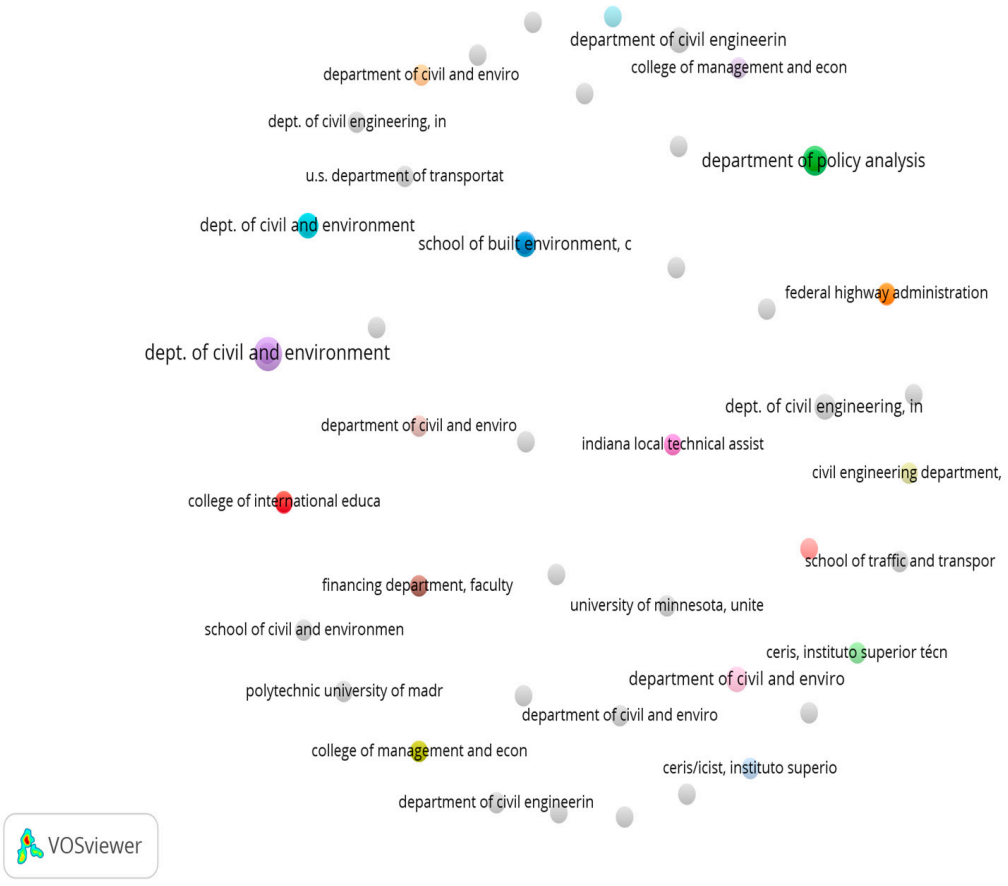

Figure 5. International cooperation networks of institutions on PPPs in road infrastructure projects.

The United States is the country that publishes the most research articles in this field (187) and has the most total citations (4693), followed by China (96 articles). However, Hong Kong has the highest index (17), followed by Spain, which has an H index of 7. The United States stands out as the country with the highest volume of articles published in this line of research 187 in total. China ranks second in the number of articles published, with 96. Regarding impact indexes, Hong Kong ranks first with an H index of 17, while Spain ranks second with an H index of 7. On the other hand, Australia has the highest average number of citations (52.85), while Hong Kong (52.42) and the United Kingdom (44.76) follow closely behind.

Finally, there is a low trend toward international cooperation in general, with only Hong Kong (66.7%), Australia (61.7%), and the United Kingdom (51.6%) showing cooperation rates above 50%. Apart from these three countries and China (43.8%), there are limited numbers of international collaborators in each country.

Table 7. Top 10 most productive countries.

Country	A	TC	%	TC/A	H Index	D(t)		NC	Main Collaborators	IQ (%)	TC/A	
						1993–2007	2008–2022				CI	NCI
United States	187	4693	25%	25.10	2	44	143	32	China, Canada, India, Australia, Thailand	33.7%	51.40	11.73
China	96	1871	13%	19.49	2	2	95	15	United States, Hong Kong, Australia, Japan, Taiwan	43.8%	25.98	14.44
United Kingdom	64	3050	9%	47.66	3	10	54	21	Spain, Ireland, Turkey, United States, Australia	51.6%	75.94	17.55
India	59	935	8%	15.85	4	4	55	5	United States, Netherlands, South Africa, South Africa, United Arab Emirates, United Kingdom	22.0%	11.31	17.13
Australia	47	2484	6%	52.85	2	1	46	25	Australia, China, United States, Hong Kong, New Zealand, New Zealand	61.7%	77.69	12.83
Spain	35	718	5%	20.51	7	1	34	10	United States, United Kingdom, Australia, Belgium, Brazil	40.0%	26.93	16.24
Canada	28	490	4%	17.50	6	6	22	6	United States, China, Cyprus, France, Saudi Arabia, France, Saudi Arabia	42.9%	17.25	17.69
Hong Kong	24	1258	3%	52.42	17	4	20	11	China, Australia, United States, Ireland, Iran	66.7%	47.69	61.88
Portugal	20	243	3%	12.15	3	0	20	5	Brazil, Hungary, Slovenia, United Kingdom, United States	25.0%	3.80	14.93
Netherlands	14	263	2%	18.79	6	1	13	9	Australia, Belgium, Chile, China, Colombia	42.9%	19.17	18.50

(A): total number of documents published; (TC): total citations received; (TC/A) average total citations received; (H index) Hirsch index in the line of research; (D(t)): total number of documents published in each subperiod; (CI) cooperation index; (TC/A CI): average number of citations in international cooperation; (TC/A NCI): average number of citations without international cooperation.

Figure 6 illustrates the countries' international cooperation network. An interaction of at least five published documents was selected, obtaining 41 countries grouped into eight clusters. As shown in Table 7, the United States, China, and the United Kingdom are the countries with the highest number of publications, and, as they are in the center of the map, they are the countries around which the different international cooperation clusters revolve.

Table 8 represents the most productive journals in road PPP research. The primary metrics analyzed are the total number of articles published, the total and average number of citations received, the Hirsch index in the research line on road PPP of the journal in SJR Scimago, the publisher, and the number of research articles in each period of the research line (Figure 2).

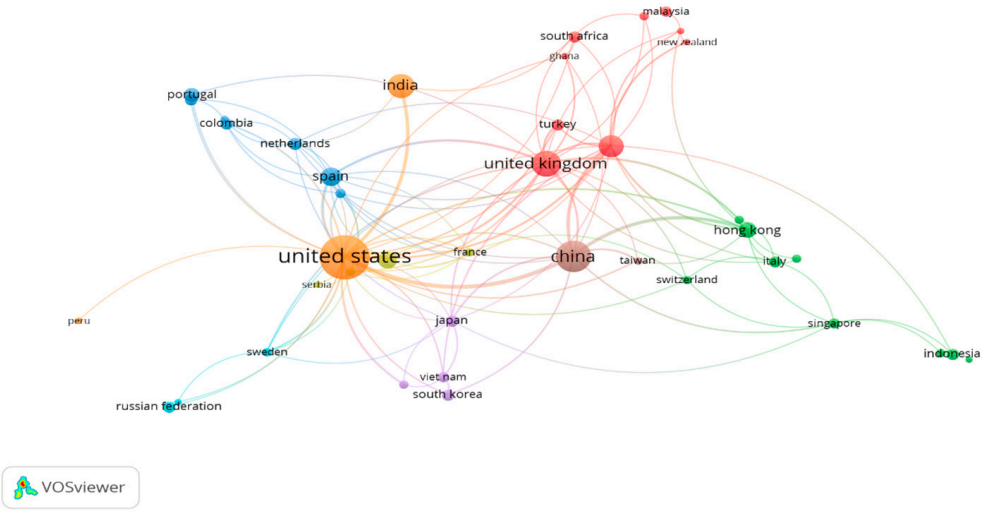

Figure 6. International cooperation network of countries international cooperation networks of institutions on PPPs in road infrastructure projects.

Table 8. Top 10 most productive journals.

Journal	A	TC	TC/A	H Index Articles	H Index Journal	SJR (2022)	Subject Area and Category	Publisher	At		C
									1993–2007	2008–2022	
Transportation Research Record	36	176	4.89	8	141	0.62 Q2	Civil and Structural Engineering (Q2); Mechanical Engineering (Q2)	US National Research Council	12	24	United States
Journal Of Construction Engineering And Management	30	956	31.87	17	129	1.15 Q1	Building and Construction (Q1); Civil and Structural (Q1); Industrial Relations (Q1); Strategy and Management (Q1)	American Society of Civil Engineers (ASCE)	5	25	United States
Transportation Research Part A Policy And Practice	21	852	40.57	16	153	2.03 Q1	Aerospace Engineering (Q1); Business, Management and Accounting (miscellaneous) (Q1); Civil and Structural Engineering (Q1); Management Science and Operations Research (Q1); Transportation (Q1)	Elsevier Ltd.	4	17	United Kingdom
Journal Of Management In Engineering	17	334	19.65	12	87	1.65 Q1	Engineering (miscellaneous) (Q1); Industrial Relations (Q1); Management Science and Operations Research (Q1); Strategy and Management (Q1)	American Society of Civil Engineers (ASCE)	1	16	United States
Construction Management And Economics	15	650	43.33	12	105	0.76 Q1	Building and Construction (Q1); Industrial and Manufacturing Engineering (Q1); Management Information Systems (Q1)	Taylor and Francis Ltd.	4	11	United Kingdom
Journal Of Infrastructure Systems	13	249	19.15	9	76	0.75 Q2	Civil and Structural Engineering (Q2)	American Society of Civil Engineers (ASCE)	2	11	United States

Table 8. *Cont.*

Journal	A	TC	TC/A	H Index Articles	H Index Journal	SJR (2022)	Subject Area and Category	Publisher	At		C
									1993–2007	2008–2022	
Built Environment Project And Asset Management	12	165	13.75	7	28	0.54 Q1	Architecture (Q1); Building and Construction (Q2); Civil and Structural Engineering (Q2); Engineering (miscellaneous) (Q2); Management Science and Operations Research (Q3); Urban Studies (Q2)	Emerald Group Publishing Ltd.	0	12	United Kingdom
Transport Policy	12	277	23.08	7	113	1.85 Q1	Geography, Planning and Development (Q1); Law (Q1); Transportation (Q1)	Elsevier Ltd.	0	12	United Kingdom
Case Studies On Transport Policy	11	107	9.73	6	31	0.72 Q1	Geography, Planning and Development (Q1); Transportation (Q2); Urban Studies (Q1)	Elsevier BV	0	11	Nether-lands
ENR Engineering News-Record	11	2	0.18	0	9	0.1 Q4	Building and Construction (Q4); Business, Management and Accounting (miscellaneous) (Q4); Civil and Structural Engineering (Q4)	McGraw Hill	2	9	United States

(A): Total number of published articles; (TC: Total number of citations; (TC/A): Average number of citations per published article; (H index articles): H index of the articles of the research line; (H index journal): H index of the journal; (SJR): SCImago Journal Rank; (C): Country.

A total of 50% of these journals are of North American origin, while the other 50% come from Europe. Of the 341 journals that published research articles (Table 2), those in Table 7 captured 178, 24% of the total scientific production disseminated through this medium. This indicates that, although there is a high number of journals, these are the references in the line of research, which is also supported by the number of citations received, the high average number of citations per research article published, the high Hirsch indexes, and the very high rating of their different research areas in the SJR Scimago. Notably, 10 journals started publishing during the exponential growth phase, while the other seven did so practically in the emergence phase. The most cited article in the research pipeline is "Tolling heavy goods vehicles" [54], published in Transportation Research Record.

5. Research Topics and Trends in Public–Private Partnerships in Road Infrastructure Projects (Q5)

Keyword co-occurrence analysis is a method commonly used in bibliometric studies to visualize the evolution of a particular research sequence over time [55,56]. This method is based on the assumption that documents sharing the exact keywords are similar in content [57,58]. This method generates a keyword map based on co-occurrence, which determines the frequency with which documents appear together based on their titles, abstracts, and keywords.

Figure 7 shows the keyword map according to the co-occurrence method in the research line of PPPs in road infrastructure projects. For a total of 2916 keywords, an interaction of at least 12 occurrences was selected, generating 77 words. Subsequently, a filtering process was carried out to eliminate keywords unrelated to the topic under study, thus avoiding erroneous results and conclusions. In total, 33 keywords were analyzed. The bubble sizes in the graph indicate how many times each word was repeated in the sample. On the other hand, the lines connecting the dots show the words that frequently appear together in the article.

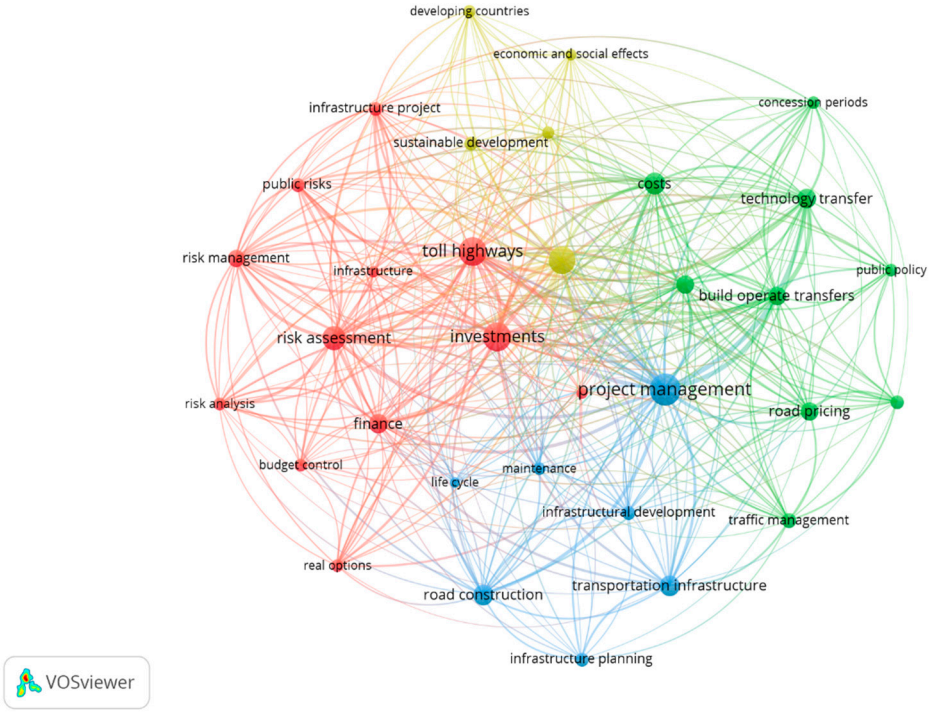

Figure 7. Keyword network on PPPs in road infrastructure projects.

We will perform a cluster analysis based on the results obtained in the co-occurrence method. We obtained four clusters or groups of keywords that determine the main research topics addressed in the area of knowledge. These groups are interrelated, without any of them being positioned in the center of the map, which shows that there is no predominant theme in the line of research but that they all have a similar relevance. The main characteristics of the identified clusters are described below.

Cluster 1: Financial management.

This is represented in the red cluster, composed of 12 keywords. Table 9 shows the keywords contained in the cluster. According to the values obtained from the co-occurrences, they are in 405 research articles (38.03% of the sample) that refer to PPPs in road infrastructure projects. Also, within this cluster, the word "investments" stands out, with 83 occurrences, and is the most used keyword in the line of research.

Table 9. Keywords: financial management cluster.

Keyword	Occurrences	Total Link Strength
Budget control	16	43
Finance	39	127
Government	13	26
Infrastructure	13	48
Infrastructure project	20	85
Investments	83	245
Public risks	19	83
Real options	16	66
Risk analysis	16	77
Risk assessment	57	200
Risk management	32	120
Toll highways	81	261

In the face of budgetary constraints and inefficiency in infrastructure provision through the TPW model, many governments have opted for the PPP model to cover the infrastructure deficit [59]. Over the past few decades, road infrastructure PPPs have evolved

in two phases, moving from a private development model into a collaborative one [60]. Given the use of PPPs in most countries, there is a recognized need to identify the most relevant risks at the planning stage to distribute them equally between the public and private sectors. This will allow both sectors to establish strategic measures to mitigate them [61]. Identifying and assessing investment risk is paramount [62], as well as the risks associated with demand during the project operation phase [63].

Cluster 2: Costs and pricing system.

This green cluster comprises nine keywords in 263 published documents (24.69% of the sample). The keyword "costs" has 46 occurrences and is the most used in cluster 2. Table 10 represents the number of occurrences and link strength of the keywords.

Table 10. Keywords contained in the topic costs and pricing system.

Keyword	Occurrences	Total Link Strength
Build operate transfers	36	180
Concession periods	16	56
Costs	46	157
Privatization	35	137
Public policy	16	52
Road pricing	34	85
Technology transfer	37	171
Traffic management	24	59
Transportation policy	19	54

PPPs have become a mechanism for raising private funds to acquire public services and infrastructure [64]. In developing countries, build–operate–transfer (BOT) PPPs have been adopted to finance necessary infrastructure projects that drive economic growth and development [65]. Under BOT contracts, the government bestows the concessionaire the right to finance, construct, and operate the projects during the concession period. After the concession period ends, the concessionaire gives back the rights of the project to the government [66]. In this context, the concession period, toll collection, and capacity are three essential variables in BOT highway projects [67]. Determining the concession period, roadway capacity, and user charges is important in infrastructure planning and management [68].

Cluster 3: Privatization of transport infrastructure services.

This cluster is represented by the blue color and is composed of seven keywords that are present in 252 research documents (23.66% of the sample). The keyword "Project management" is the most used word in cluster 3, with 99 occurrences. Table 11 shows the number of occurrences and the strength of the keyword links.

Table 11. Keywords in the privatization of transport infrastructure services topic.

Keyword	Occurrences	Total Link Strength
Infrastructural development	20	57
Infrastructure planning	19	34
Life cycle	12	26
Maintenance	17	45
Project management	99	339
Road construction	44	104
Transportation infrastructure	41	95

Transportation infrastructure investments play a vital role in a country's development and have a particular impact on rural areas by improving connectivity between regions [69]. However, budget constraints to implement infrastructure projects and the need to close infrastructure gaps have led governments to explore financing alternatives such as PPPs [70]. PPPs are not a short-term solution for financing infrastructure projects, but the public and

private sectors must assess any potential risks that may arise throughout the project's life cycle [71]. The SWARA (stepwise weighted assessment ratio analysis), COPRAS (complex proportional assessment), and EDAS (evaluation based on the distance to average solution) methods have great potential in PPP risk assessment [72]. Therefore, it is essential to establish risk mitigation and destruction arrangements to guarantee the success of PPP projects [73].

Cluster 4: Sustainability.

The dark yellow represents this cluster and consists of five keywords in 145 published research papers (13.62% of the sample). The most used words in this cluster are "highway planning" and "sustainable development". Table 12 shows the number of occurrences and the strength of the links of the keywords.

Table 12. Keywords in the sustainability theme.

Keyword	Occurrences	Total Link Strength
Cost–benefit analysis	16	54
Developing countries	18	46
Economic and social effects	15	36
Highway planning	76	275
Sustainable development	20	33

Sustainability and PPPs are linked to the Sustainable Development Goals (SDGs) because public–private contracts enable the provision of essential services and infrastructure [74]. Under that context, sustainability is becoming more critical in implementing infrastructure projects, as stakeholders demand ethics, environmental respect, and economic efficiency throughout the project lifecycle [53]. For a project to be sustainable, it must address all three dimensions of sustainable development [17,75]; social sustainability encompasses social benefits and equitable infrastructure, while environmental sustainability is focused on the impact on health and the environment. Finally, economic sustainability refers to the government's capacity to fulfill the financial obligations that arise from infrastructure investments, both short and long-term [76].

Figure 8 shows the evolution of the research line and its different topics over time. The dark colors show the keywords addressed first, while the lighter shades represent the most recent keywords, indicating a significant increase in the volume of key terms within a group in the last few years. This suggests that increasing importance is given to road PPP topics. Consequently, all related issues will be addressed, and the research line will provide multidisciplinary solutions in the coming years.

It also shows the evaluation with which the keywords have appeared so that those that are more obscure appeared in the past and those that are lighter have emerged more recently. The latter determine research trends: concession periods, budget control, life cycle, real options, infrastructure projects, and sustainable development.

In this way, there are still important research gaps in the PPPs in road infrastructure projects. Namely, for each of the research topics detected (Figure 7), depending on their evolution over time (Figure 8) and the most used keywords (Table 13), the following subjects are suggested.

In the economic–financial evaluation of PPP projects, there is a need to look more closely at risks [77]. Regarding risk mitigation strategies, special attention must be paid to financial models, i.e., assessing, allocating, and controlling project financial risks [78]. On the other hand, risk allocation and risk management are crucial elements for the success of a PPP project, as inefficient risk allocation could lead to costly negotiations or even project failure. Although risk factors have been identified in the literature based on countries with mature PPP systems, such as the UK, Australia, and Spain, the various risk factors and risk allocation strategies in developing countries have not yet been fully explored. Therefore, future research needs to consider local specificities in risk allocation [79].

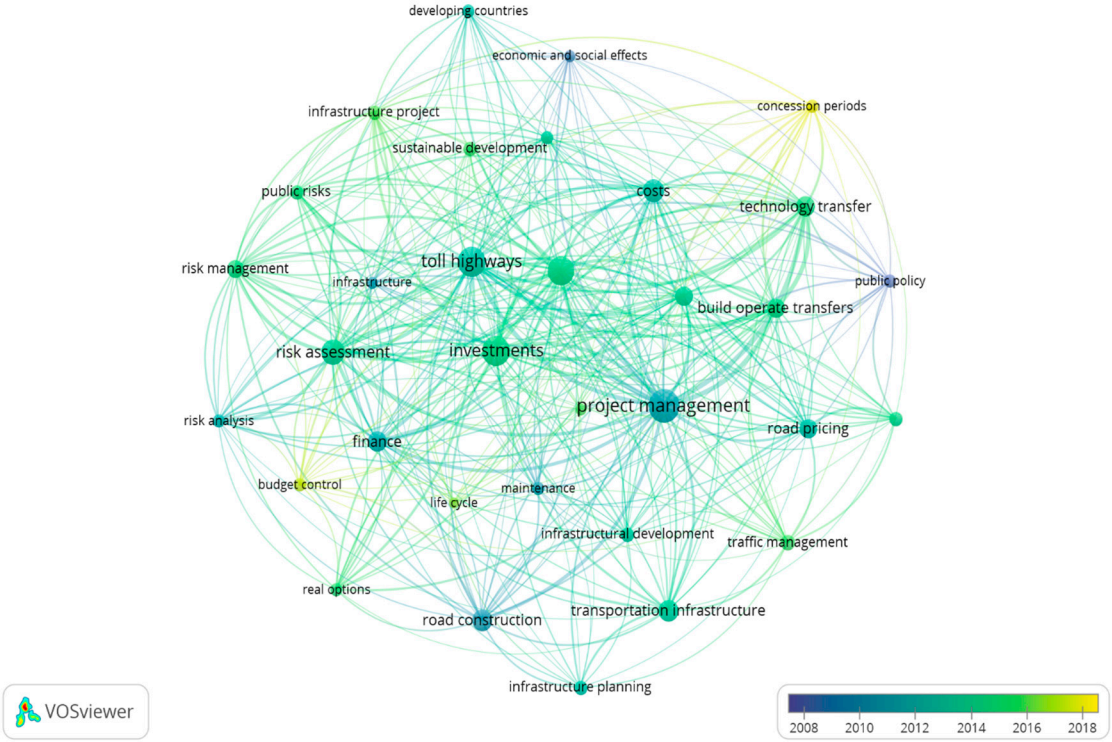

Figure 8. Evolution of PPPs research in road infrastructure projects.

Table 13. Future research lines.

FINANCIAL MANAGEMENT	T1: Economic and financial viability assessment. T2: Risk mitigation strategies. T3: Risk allocation and management.
COSTS AND PRICING SYSTEM	T4: Toll pricing mechanisms. T5: Determination of the concession period.
PRIVATIZATION OF TRANSPORT INFRASTRUCTURE SERVICES	T6: Government guarantees as a tool for attracting private investment. T7: Tendering, awarding and control of contracts.
SUSTAINABILITY	T8: Innovation in project life-cycle design. T9: Sustainable practices in infrastructure construction and operation. T10: Ways of reducing carbon emissions.

The quantification of tolls in PPP projects involves considering factors that allow for fair and sustainable pricing. While various methodologies have been proposed, such as financial analysis, demand assessment, and investment and maintenance considerations, the complexity lies in balancing the interests of the parties involved. The search for an efficient and equitable pricing model remains a central challenge in the successful implementation of PPP projects [80]. Likewise, the determination of the concession period is a crucial parameter in PPP agreements and needs to be addressed in detail, taking into account the interests of the parties involved. The ineffective design of this aspect can lead to post-contractual renegotiations or even early termination of the contract. Most of the models proposed in the literature to determine this period assume the availability of information, which is not always available. Therefore, there is a need to further develop a model to establish the length of the concession period in situations where there is uncertainty about project revenues [81].

On the other hand, government guarantees are presented as a tool to attract private investment in PPP projects. These guarantees offer security and risk mitigation to private investors while encouraging private sector participation in infrastructure development. Effective implementation of government guarantees will contribute to building investor confidence, thus facilitating the successful financing and implementation of PPP projects. However, methodologies for identifying maximum and minimum levels of government guarantees should be further developed [82]. The bidding, awarding, and control phases of PPP contracts for highway projects are crucial to the project's success. Tendering evaluates proposals, awarding selects the right bidder, and contract control ensures contract compliance. However, concerns about potential defaults, disputes, and financial problems may arise, which underlines the importance of transparency and communication in addressing these challenges and ensuring the efficient execution of the PPP project.

Finally, in innovations in the life-cycle design of projects, it is essential to delve into the use of building materials that are eco-friendly, recycled, or from renewable sources to reduce the carbon footprint and decrease the exploitation of natural resources [83]. Furthermore, regarding sustainable practices in the construction and operation of infrastructure, it is essential to deepen the adoption of such materials for PPP roads, specifically the use of recycled materials, industrial by-products, and innovative technologies that optimize performance and prolong the life of the infrastructure [84]. In terms of reducing carbon emissions, the need to deepen the mitigation of emissions during road maintenance by making roads more efficient is highlighted [85].

6. Discussion and Conclusions

This study aims to analyze the research conducted on PPPs in road infrastructure projects globally between 1993 and 2022 through the bibliometric analysis of 734 research articles registered in the Scopus database. The number of published articles, authors, and co-authors, citations, average number of citations per article, and countries and journals of publication were investigated, showing that there has been a general increase in research interest in PPPs in road infrastructure projects, especially in the period 2008–2022, possibly driven by the global financial crisis of 2008.

There are numerous studies in the literature on public–private partnerships (PPPs) in infrastructure projects; for example, Tallaki and Bracci (2021) reviewed risks and their management [86]. Ahmed and Garvin (2022) analyzed critical success factors and key performance indicators of PPPs [87]. Pu et al. (2021) presented the evolution and trends of PPP research in China [15]. This study distinguishes previous studies, given that it presents the main authors, countries, institutions, and international cooperation networks, as well as the main research topics and future lines of research. In addition, this study provides a global review of PPPs in road infrastructure projects over the last 30 years.

Our findings show that the authors with the most products are Vassallo, J.M.; Guevara, J.; and Wibowo, A., with nine, eight, and eight published research articles, respectively. It is worth noting that 40% of the authors are of Asian origin, which could be because Asian governments have promoted, in recent years, the development of PPP projects for the provision of infrastructure and public services, which has generated a strong interest in the part of the international academic community in their study. Among institutions, the Polytechnic University of Madrid (Spain) was the most productive institution in terms of publishing research articles on PPPs on roads (18). This could be because this university has had a line of research focused on the economics and financing of transport infrastructure for over thirty years. It analyzes regulation, bidding, economic impact, pricing systems, and, in general, road planning and management. The enormous interest aroused by the scientific community in this line of research is because Spain has been a pioneer in the development of concessions for the construction and operation of toll roads since its first concession project dates back to the end of the 1960s. The experience in this sector has been exported to other countries worldwide. In turn, our findings identified that the United States generated the most significant number of research articles on highway PPPs (187). In

addition, the United States (187), China (96), United Kingdom (64), India (59), Australia (47), Spain (35), Canada (28), Hong Kong (24), Portugal (20), and the Netherlands (14) are the countries that have published the most during the entire study period. However, it should be noted that 40% of the countries that do the most research in this line of research are of European origin, which could be because, in this area, the European Commission has encouraged the use of this type of financing for infrastructure projects and this has generated interest in many researchers from European institutions.

The analysis of the thematic areas of research reveals that, throughout the entire period that was analyzed, "Engineering" has been the primary area (29.31%), followed by "Social Sciences" (23.51%), "Business, Management and Accounting" (17.10%), and "Economics, Econometrics and Finance" (6.95%), with these four thematic areas accounting for 76.87% of the publications. It is worth noting that the area of "Economics, Econometrics and Finance" has been gaining considerable ground in recent years, which could be explained by the financial crisis at the international level and the growing need to address instruments to facilitate PPP and thus make investment in road infrastructure more sustainable. This means the main issues discussed in road PPP are related to financial management, costs, pricing systems, privatization of transport infrastructure services, and sustainability. Financial management is currently the most relevant line for the scientific community. At the same time, sustainability, which promotes sustainable technologies in road construction and maintenance, will capture research attention shortly.

Consequently, it is concluded that after the global financial crisis of 2008, the PPP market in the road sector experienced a slowdown. Meanwhile, in Latin America, the recovery was rapid, unlike the EU, where the PPP market took longer to recover [43]. This phenomenon has awakened the academic community's interest in investigating this line of research, leading to a continuous increase in articles, authors, countries, citations, and scientific journals in the last decades. The Sustainable Development Goals (SDGs) can inspire researchers and practitioners to expand their points of view to address the implications of PPPs on roads. In addition, it is crucial to highlight the importance of the 17 SDGs, emphasizing the need to foster international collaboration to achieve sustainable development. This bibliometric analysis makes it possible to understand and assess the suitability of different actors, promoting and sharing knowledge and experiences, providing clues, and creating connections between relevant clusters and strands for the future.

Finally, this study has some limitations that provide the basis for the development of future research to complement the results obtained. One of the limitations of this work is that the results are not generalizable due to the specific characteristics of each project and the countries' social, political, and economic conditions. Therefore, we recommend that in the future, the results collected here be compared with the specific characteristics of the specific case. On the other hand, using other databases, such as the Web of Science or Google Scholar, or broadening the type of research documents to include book chapters or papers presented at conferences, could expand the number of search documents and identify other relevant topics. At the same time, this would also be possible by broadening the search terms to avoid excluding records of scientific value, allowing for greater completeness of the analysis. The VOSviewer software tool was used to visualize the cluster data, which provides results that may differ from those obtained using other software. Lastly, a research design based on a more exhaustive content analysis would allow us to investigate the identified research topics more deeply.

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