A BIBLIOMETRIC MAPPING OF RESEARCH TRENDS AND DIRECTIONS ON THE RELATIONSHIP BETWEEN INFRASTRUCTURE AND RURAL DEVELOPMENT

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ABSTRACT

This paper explores how infrastructure is connected to rural development by analysing trends in academic research over the past three decades. Infrastructure is essential for improving the quality of life and supporting economic growth in rural areas. As rural regions often face challenges like isolation, limited services and population decline, developing adequate infrastructure is seen as a key solution. To better understand how this topic has been studied, the research uses a bibliometric method based on articles indexed in the Web of Science™ Core Collection. A total of 166 publications from 1993 to 2025 were analysed using the VOSviewer software. Three main clusters were identified: Socio-political dimensions of rural infrastructure, Sustainable transformation and rural development, Economic performance and public infrastructure. The paper highlights the increasing international interest in these topics, with strong contributions from countries like China, the United States and Romania, but still international collaboration remains modest.

Introduction

In recent decades, rural development has become one of the key priorities on both national and European policy agendas, particularly in light of the challenges posed by territorial equity, social cohesion and economic sustainability. Rural areas, often

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characterized by low population density, considerable distance from urban centres and underdeveloped infrastructure, face significant difficulties in integrating into an increasingly competitive and digital economy. In this context, infrastructure development is not merely a technical goal, but a fundamental condition for the sustainable transformation of rural spaces (OECD, 2016).

The concept of "rural development" plays a central role in the analysed network, being closely linked to key terms such as policy, infrastructure, poverty, growth and sustainable development. This shows its importance in connecting economic, social and institutional aspects of rural transformation. Likewise, "rural infrastructure" appears as an important term in the literature, mentioned frequently and associated with ideas like economic progress, inequality and public policy. Studies increasingly describe rural infrastructure as a key factor in reducing poverty, improving living conditions and supporting local development. In the academic literature, these components are often described as the "backbone" of balanced territorial development (World Bank, 2009). Their absence or underdevelopment leads to isolation, high living costs, accelerated migration and a reduced capacity to attract investment. Numerous international studies emphasize that investments in infrastructure directly stimulate rural economies by supporting local markets, reducing production costs and improving labour mobility (Heijman and Van der Heide, 2000; Satish, 2007; Lenz et al., 2017; European Commission, 2021; European Commission, 2024).

The contemporary discourse on rural development increasingly highlights infrastructure as a decisive factor shaping social and economic transformation. Jiang et al. (2021) analyze the dynamic relationship between rural infrastructure and energy consumption patterns. Building on this perspective, Luo et al. 2022 investigate the coupling mechanism between rural revitalization and urbanization through a system coordination model. The empirical assessment of Ya'an (2011–2018) shows that sustainable rural progress depends on the coordinated growth of rural and urban systems. Infrastructure integration, therefore, emerges as a central pillar for achieving balanced regional development within the broader urbanization process. Kumar et al. (2022) extend this analysis to rural tourism, identifying infrastructure as a core enabler of tourism-based economic diversification. Wang, (2022) integrates technological innovation into the rural development discourse, employing multisensor and geographic big data to map and evaluate tourism resources. Liu (2022) explores gender inequalities in rural education and landownership, revealing how infrastructure deficits perpetuate socio-economic disparities. Yin et al. (2023) examine rural traffic infrastructure from a safety perspective, focusing on night driving conditions. Gong et al. (2023) explore the influence of smart city initiatives on urban–rural collaboration. At the same time, social infrastructure plays a crucial role in building human capital and reducing social exclusion (Yu et al., 2024). A relatively new, yet increasingly important topic in the scientific literature concerns digital infrastructure in rural areas. Access to high-speed internet, e-government platforms, electronic banking services and online markets is reshaping the socio-economic dynamics of rural communities (Salemink et al., 2017;

Arcuri et al., 2023; Ma et al., 2023). Supporting microenterprises and social enterprises in rural areas directly depends on the availability of such enabling infrastructure (FAO, 2019; Popa, 2023). Well-developed infrastructure also stimulates local cooperation, attracting public-private partnerships, associative forms and community-driven initiatives (Cheshire et al., 2015). Rural development is a complex process, shaped by the action of economic, social, cultural, environmental and governance-related factors (Calatrava-Requena, 2016). The progress in rural areas depends on how these elements are used and put together (Popa et al., 2024). It is not enough to just support agriculture; is needed an integrated approach that allows people to use public services, encourages rural entrepreneurship and improves digital connectivity (Wang et al., 2025). The infrastructure has to play a central role in achieving these goals. Over the past two decades several research directions have emerged, including the economic impact of infrastructure investments, the link between social infrastructure and migration, the role of digital infrastructure in reducing rural exclusion and the integration of green and sustainable infrastructure into local development strategies (Wubayehu, 2020; Hindersah et al., 2020; Kalinowski and Rosa 2021; Maloney et al., 2024). In this context, a bibliometric analysis of current trends and research directions becomes necessary for organizing the existing body of knowledge and identifying theoretical or methodological gaps. Bibliometrics quantifies the volume of scientific output, and maps author networks, research themes and institutional affiliations, offering a coherent overview of the field (Aria and Cuccurullo, 2017).

This study aims to explore the relevant scientific literature in order to understand how rural infrastructure is conceptualized and examined in relation to territorial development. By analysing keyword networks, thematic clusters and the temporal evolution of publications, the research highlights the main directions in the field. The bibliometric approach is based on data extracted from the Web of Science™ Core Collection, known for its relevance and international coverage. The VOSviewer software is used to visualize semantic networks, enabling a qualitative interpretation of quantitative results.

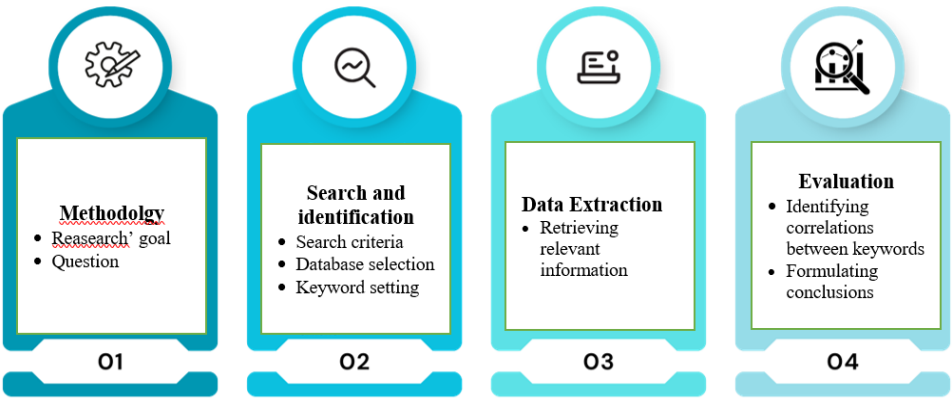
Methodology used in the bibliometric analysis

Infrastructure, in its various forms and classifications and regardless of whether it is owned by a public or private entity (Torrisi, 2009), is an essential component of human civilization. Rural development, in turn, is a key process for reducing territorial disparities, improving quality of life and strengthening social and economic cohesion within a country (Atkinson, 2017). It is natural to examine the link between the creation of infrastructure and the emergence of signs of development in the communities that use it (Cantu, 2017).

The bibliometric analysis conducted in this paper followed, as suggested in the specialized literature (Donthu et al., 2021; Pantović et al., 2023; Seočanac et al., 2024; Davidović et al., 2025), four main steps: defining the methodology, searching for and identifying relevant information, collecting data and interpreting the results. The

sequence of the methodological steps is illustrated schematically in Figure 1, providing a concise overview of the workflow followed in this study. The scientific approach began with the definition of a clear research direction, formulated as a central question focusing on how the academic literature has reflected the relationship between the major concepts of rural infrastructure and rural development: "To what extent does the existing scientific literature reflect relevant connections between the concepts of rural infrastructure and rural development?". This was accompanied by a secondary question aimed at identifying patterns of conceptual interconnection in existing research: "How is the interdependence between these two concepts addressed in academic publications?"

Figure 1. The steps applied in the bibliometric analysis

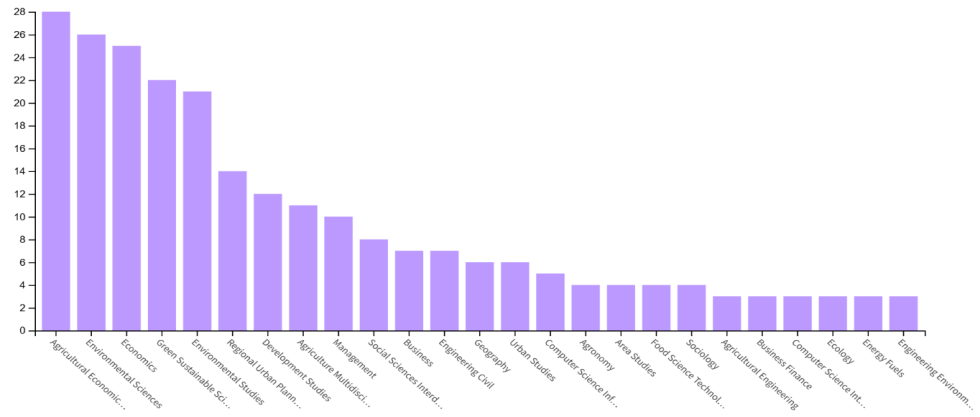


Implementing the methodology and exploring the results

During the bibliographic exploration phase, relevant terms were identified to define the analytical framework, logically selected based on the initial research questions. These included: "rural infrastructure", "public infrastructure", "economic infrastructure", "basic infrastructure", "business infrastructure", "rural development", "rural progress", "rural growth", "rural transformation", "welfare of rural population" and "improvement of rural livelihoods".

To collect bibliometric data, the Web of Science™ Core Collection (WoS) was used, providing a solid foundation for bibliometric analysis (Clarivate, 2025). The data extraction process was carried out between May 22 and 25, 2025. To query the WoS database, a search chain was formulated using the logical operators "AND" and "OR", applied in the "Topic" field, which includes the title, abstract and keywords of publications. The query combined two sets of relevant terms as follows: Topic search (TS) = (("rural infrastructure" OR "public infrastructure" OR "economic infrastructure" OR "basic infrastructure" OR "business infrastructure") AND ("rural development" OR "rural progress" OR "rural growth" OR "rural transformation" OR "welfare of rural population" OR "improvement of rural livelihoods")).

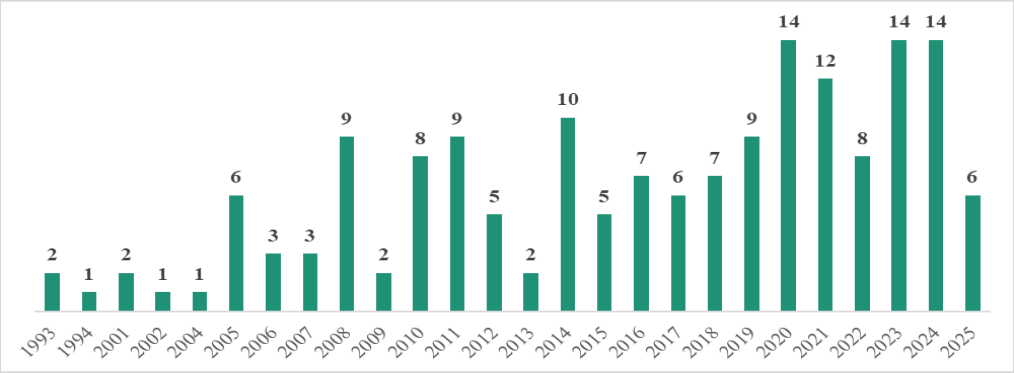
Figure 2. Top 25 scientific fields – number of indexed articles per category



Source: Processing based on the number of research articles identified in WoS, classified by category

As a result of the selection process through bibliometric analysis, 166 relevant scientific articles were identified, published between 1993 and 2025. These publications address the investigated topics from multiple thematic perspectives and are distributed across 64 distinct scientific fields, according to the classification provided by WoS, reflecting both the disciplinary diversity and the cross-cutting nature of the analysed literature. Figure 2 presents a visualization of the 25 most frequently represented categories in which the articles were indexed. A single article can be assigned to multiple categories depending on its content and the classification criteria applied at the time of inclusion in the WoS database. For this reason, the total number of entries associated with the first 25 categories represented in the Figure 2 may exceed the absolute number of 166. The visual analysis of the 25 most frequently occurring scientific categories reveals that economic and environmental fields are dominant in the selected literature. Additionally, the existence of articles in the categories "Green Sustainable Science Technology" (22 articles), "Environmental Studies" (21 articles) and "Development Studies" (12 articles) shows the growing attention of academia to ecological and sustainable aspects of infrastructure and rural development. In the agricultural sphere, "Agriculture Multidisciplinary" (11 articles) suggests an integrated approach to the topic, while the presence of "Management" (10 articles) and "Social Sciences Interdisciplinary" (8 articles) points to the involvement of social and organizational research in understanding the phenomena analysed. Other notable categories include "Business" (7 articles), „Engineering Civil" (7 articles), „Urban Studies" and "Geography" (6 articles each) and "Regional Urban Planning" (14 articles), indicating a concern for territorial development and urban-rural infrastructure. Overall, the thematic distribution reveals the highly interdisciplinary nature of the research, capturing the complex interdependencies between infrastructure development and rural dynamics.

Figure 3. Temporal distribution of published articles



Source: Own processing of annual data on scientific articles in WoS

From a temporal perspective, the relevant articles cover a long period, from 1993 to 2025. However, their distribution over time is not uniform, with clear differences between early and recent phases. The first two decades are marked by a low and fluctuating number of publications. After 2015, a clear upward trend emerges, signalling a shift in publishing dynamics. The 2020-2024 interval is the most prolific, reflecting the growing scientific interest in topics related to rural infrastructure and territorial development (Figure 3).

To analyse the bibliometric relationships between fundamental concepts, the final step of the methodology involved the use of VOSviewer (version 1.6.20), a widely recognized tool for mapping and interpreting networks of publications and terms in academic literature. This software was chosen for its open-access nature, excellent compatibility with the Web of Science (WoS) database and proven reliability in previous reference studies (Gillani et al., 2022; Van Eck & Waltman, 2010).

The next step involved exporting and uploading the 166 selected articles from WoS into VOSviewer, which generated the essential files containing detailed information about the extracted terms (including their frequency), semantic links between them and their spatial positioning. To examine how semantic relationships between key concepts are structured in the selected literature, a co-word occurrence analysis was performed using the bibliometric files generated. The core of the investigation focused on the concepts central to the research and how they are associated in existing studies. After processing the data, out of 860 identified keywords, 25 terms met the inclusion criterion of appearing at least four times across the analysed documents.

Regarding the analysis of international collaboration, the co-authorship by country function was used to explore the geographical dimension of author networks. By applying a minimum threshold of three documents per country, 21 out of 56 countries met the criterion, reflecting significant international participation in the researched domain.

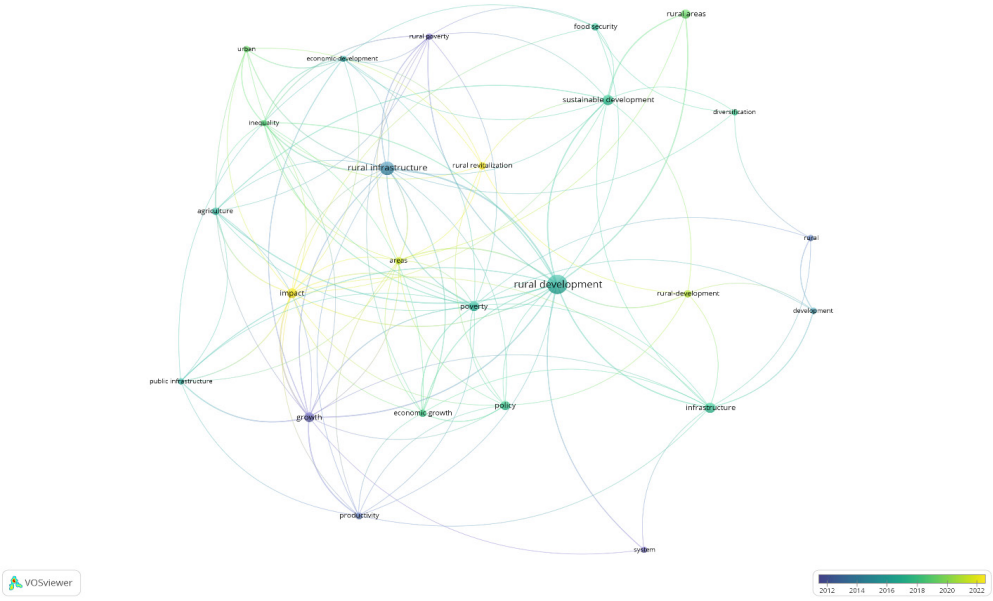
Discussions. Exploring the relationships between infrastructure and rural development through bibliometric analysis of the three thematic clusters identified with VOSviewer

The analysis of how keywords were grouped was based on examination of the terms used in scientific publications, considering that terms that frequently appear together in the same articles are most likely thematically related. These terms form groups, called clusters, which represent specific and well-defined topics within the broader research field. Each cluster contains terms that are connected by their frequency of co-occurrence and the strength of their links, helping to reveal the overall structure of the literature and to identify the main themes and the relationships among key concepts. To better understand the connections between major ideas related to infrastructure and rural development, which are central topics in this study, the three thematic clusters identified using VOSviewer were analysed. To understand how these concepts are interlinked, the following section will examine in detail the density of the term network, and how it has changed over time and the content of each cluster.

Overlay Visualization of the Bibliometric Network's Temporal Evolution

The bibliometric map presented in Figure 4 was generated in VOSviewer using the overlay visualization mode. The map enables us to track how certain terms have become more prominent over time, highlighting both thematic continuities and emerging research directions. Colour interpretation, based on the temporal scale shown in the bottom right corner of the diagram, covers the period between 2012 and 2022. Terms displayed in darker shades (blue, violet) correspond to earlier studies, while lighter tones (green, yellow) reflect more recent interests in the literature. For instance, terms such as "rural infrastructure" "growth" "productivity" or "rural poverty" are mostly associated with older publications and are shown in darker colours, typically linked to the 2012-2016 period. In contrast, terms like "impact" "areas" or "rural revitalization" appear in lighter tones such as yellow or light green, indicating a growing research interest in these topics in more recent years. Between these two temporal poles, transitional terms like "sustainable development" and "rural areas" have maintained consistent relevance throughout the entire timeframe. This variation in colour provides valuable insights into the thematic evolution of research on infrastructure and rural development, allowing for the identification of current hot topics as well as promising directions for future research. Looking at the overall structure of Figure 4, there is a strong concentration in the central area of the network, dominated by terms such as "rural development", "rural infrastructure", "policy", "impact", "economic growth" and "areas".

Figure 4. Visual network overlay map



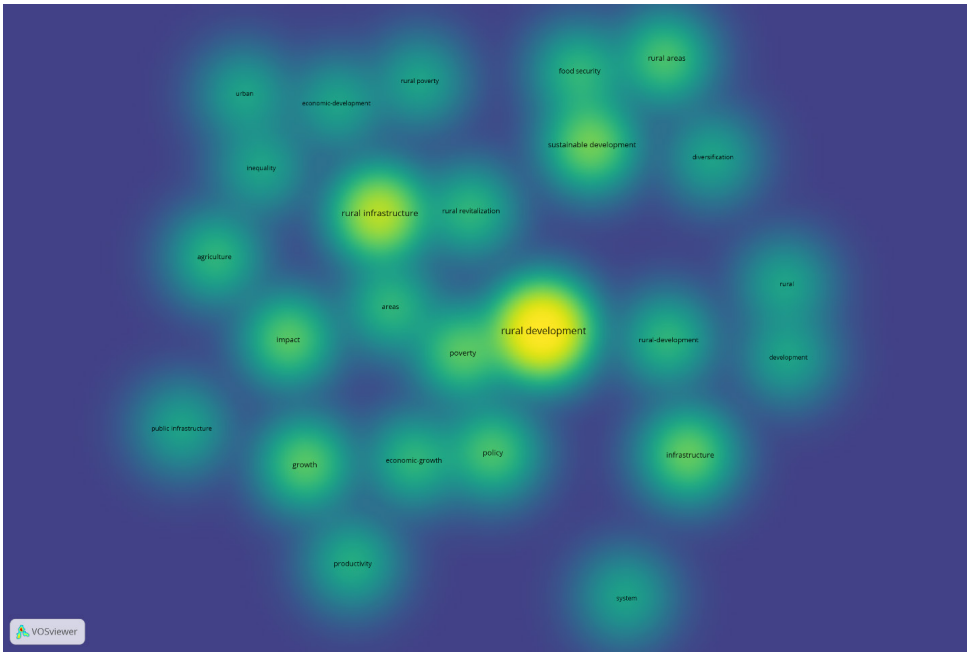
Source: View generated with VOSviewer

Density map of the bibliometric network (density visualization)

An appropriate way to show the level of interest and frequency of topics in the analysed literature is through the density visualization, which helps identify areas within the network where terms appear frequently and are strongly related, offering a clear picture of the intensity of research on certain subjects. The bright yellow areas in Figure 5, which is a density visualization generated in VOSviewer, indicate regions with the highest concentration of terms and connections, pointing to key topics that are often discussed in academic literature. In contrast, green and light blue shades represent moderate densities, while dark blue or purple areas mark the outer edges of the thematic network, where terms appear less frequently and have weaker connections, suggesting either lower scientific interest or topics that are still emerging. At the centre of the map shown in Figure 5, the terms „rural development" and „rural infrastructure" stand out clearly with bright colours, confirming their dominant position in the academic literature, forming the thematic core around which other important concepts revolve. Their presence in the highest density area indicates that they are not only frequently mentioned, but also strongly connected to other terms in the network. In close proximity to these central terms are concepts such as "impact", "poverty", "areas", "policy", "economic growth", "agriculture" and "sustainable development", marked in green-yellow tones. This indicates a moderately high frequency and a strong thematic connection to the dominant topics. These elements outline the main directions of research that support debates around rural development, emphasizing economic, social

and governance dimensions. The fact that "policy" and "economic growth" are near the core terms confirms the importance of the institutional framework and the economic dimension in addressing these issues. On the edge of the network, terms like "system", "development", "rural" or "urban" appear in bluish-green tones, which reflect lower intensity or weaker connections to the central terms.

Figure 5. Network density visualization



Source: View generated with VOSviewer

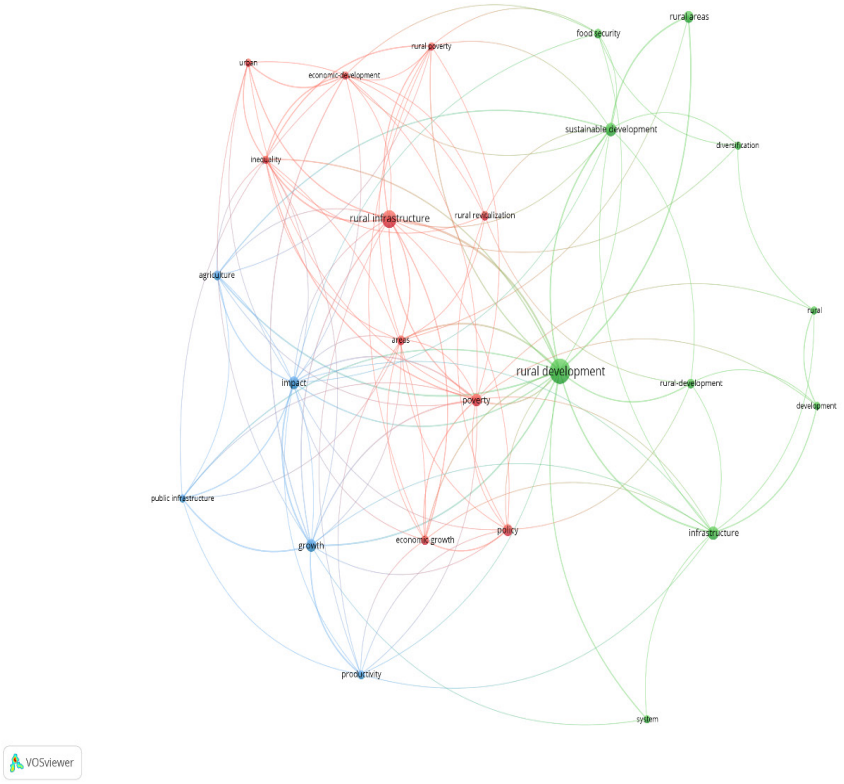
Network visualization and VOSviewer clusters

The visual map of the network provides a clear overview of the key concepts found in the analysed literature and how they are connected, making it easier to understand the overall thematic structure and the semantic relationships between the topics discussed in the research. Figure 6 presents a detailed visual representation of the semantic links between the main concepts frequently found in the literature on infrastructure and rural development, highlighting both the core areas of interest and the connections between various thematic fields. The visual analysis highlights the existence of at least three main clusters: a green cluster focused on concepts such as "rural development", "sustainable development", "rural areas", "infrastructure" and "diversification", reflecting an emphasis on sustainability and rural transformation; a red cluster centred around the term "rural infrastructure" and associated with themes such as "economic development", "rural poverty", "urban" and "inequality", which points to a socio-economic approach to rural infrastructure issues; and a blue cluster, where terms like "public infrastructure", "growth", "productivity", "impact" and "policy" appear,

clearly reflecting an economic and institutional dimension of development. The central positioning of the terms "rural development" and "rural infrastructure", along with their links to a wide range of terms from all three clusters, highlights their pivotal role in the entire network. These concepts act as connecting points between different research directions, supporting the cohesion of the overall thematic structure.

In conclusion, the term network illustrates a complex and well-connected research field, where public policy, economic performance, physical infrastructure and sustainability consistently converge around the theme of rural development. Table 1 shows details about the three clusters and their associated nodes. The interactions among the three thematic clusters reveal a coherent and densely connected conceptual network, where central terms like "rural development" and "rural infrastructure" serve as key connection points.

Figure 6. Network visualization



Source: View generated with VOSviewer

Cluster 1, shown in red and composed of 10 terms, reflects the socio-political and economic dimensions of rural infrastructure, including concepts such as "policy", "economic development", "rural poverty", "urban" and "inequality", forming a thematic core focused on analysing spatial imbalances and government interventions. The presence of terms "rural revitalization" and "areas" suggests an integrated approach that addresses not only the physical construction of infrastructure but also the social and economic improvement of rural spaces. The strong links between these terms indicate that they are frequently discussed together in the academic literature.

Cluster 2, highlighted in green and made up of 10 terms, focuses on themes related to sustainable development, rural transformation and economic diversification. Concepts like "sustainable development", "rural areas", "food security" or "infrastructure" show a clear orientation toward sustainability and adaptability to new economic and environmental conditions. Terms such as "system", "rural-development" and "diversification" point to a systemic approach, where rural development is no longer seen in isolation but as part of a broader context that includes agriculture, food security, basic services and economic mobility. As shown in Figure 6, the green cluster is strongly connected to the network's central nodes, indicating that these themes are well integrated into current academic discussions.

Cluster 3, marked in blue and containing 5 terms, addresses topics related to economic performance, public infrastructure and productivity. Although smaller in size, this cluster holds strategic relevance, linking concepts such as "impact", "growth", "agriculture", "productivity" and "public infrastructure." The position of these terms at the intersection with the other two clusters shows that economic efficiency and administrative infrastructure are often discussed alongside social and environmental concerns. This cluster complements the larger picture of rural development research by indicating measurable outcomes and the capacity of infrastructure to create both direct and indirect economic effects.

Table 1. Cluster structure and distribution of terms analysed in VOSviewer

Cluster	Identified nodes
1. Socio-political dimensions of rural infrastructure (red colour - 10 terms)	areas, economic development, economic growth, inequality, policy, poverty, rural infrastructure, rural poverty, rural revitalization, urban
2. Sustainable transformation and rural development (green colour - 10 terms)	development, diversification, food security, infrastructure, rural, rural areas, rural development, rural-development, sustainable development, system
3. Economic performance and public infrastructure (blue colour - 5 terms)	agriculture, growth, impact, productivity, public infrastructure

Source: Own interpretation of clusters resulting from VOSviewer analysis

Structurally, the network made up of 25 nodes and 120 links has a total connection strength of 176, indicating high semantic density. The terms across the three clusters do not operate in isolation but are often used together in the same scientific work, suggesting a high degree of interdisciplinary and complementarity among fields like economics, public policy, rural development and sustainability. The central nodes link all three thematic groups, contributing to strong conceptual cohesion across the network, which confirms the complex and integrative nature of current research in this field.

The main relevant terms identified in the analysis

The analysis of keywords in academic literature is an essential step in understanding the conceptual structure of the field under investigation. The frequency of terms, their position in the network and the connections they establish with other terms provide valuable insights into dominant topics, preferred research directions and the level of thematic integration.

The term "rural development" stands out as the central node in the analysed semantic network, with the highest frequency of occurrence (37 instances) and the greatest number of direct connections (18 links) to other terms in the network. It belongs to Cluster 2 (green), a thematic group focused on the sustainable transformation of rural areas. However, due to its central position in the visual representation and its dense relationships with terms from all three clusters, "rural development" plays a key connecting role across the social, economic and institutional dimensions of development. The direct connections of this term, as shown in Figure 6, include a range of key concepts such as "policy", "infrastructure", "poverty", "impact", "growth", "rural infrastructure", "sustainable development", "public infrastructure", "system", "food security" and "economic growth." These links, represented by thick lines, indicate a total connection strength of 42, reflecting not only how often these terms appear together in the literature but also their conceptual importance in the analytical framework of the topic. "Rural development" is thus embedded in discussions on infrastructure and public policy, as well as in those related to sustainability, agriculture, inequality and economic efficiency. The central position of "rural development" on the map shows that it is not treated as a separate topic, but rather as a key concept that brings together different views on territorial change, policy action and economic growth.

The term "rural infrastructure" holds a central place in the analysed semantic network, being one of the most frequently used and well-connected concepts in the entire system. It appears 18 times, establishes 15 direct links with other key terms in the network and records a total link strength of 27, indicating a high level of association with multiple topics addressed in the specialized literature. As shown in Figure 6, this term is part of Cluster 1 (red), together with concepts such as economic development, poverty, policy and urban, which together outline the political and economic dimension of rural infrastructure. The visible connections of the term "rural infrastructure" confirm its role as a linking point between the institutional, social and economic dimensions of

rural development. Among the key related terms are "economic growth", "impact", "growth", "inequality", "agriculture" as well as "policy" and "rural development". Its position near the centre of the network and its connections to nodes across all three clusters show its cross-cutting relevance. Rural infrastructure is seen not only as a physical component of development but also as a factor that supports social inclusion, economic performance and effective public policy. An important aspect of the analysis is its strong link with "poverty", "inequality" and "rural poverty", suggesting that infrastructure is seen in research as a tool for reducing gaps and improving living conditions in marginalized areas. Its connections to "impact" and "growth" also point to growing interest in measuring the effects of infrastructure on local development, in terms of added value, economic mobility and access to essential services. In conclusion, "rural infrastructure" is a key concept in the analysed thematic network, playing a dual role both as a subject of technical and institutional analysis and as a strategic means for rural development policy. Its importance in the literature is confirmed by the central position and the density of its connections, which make it an essential indicator of the potential to transform rural areas.

Limits of bibliometric analysis

Although bibliometric analysis is a powerful tool for exploring the structure, dynamics and research directions of a scientific field, it has several methodological and interpretive limitations. In this study, these limitations mainly arise from the choice of database, the method of term extraction and the parameters used to generate the visualizations.

Conclusions

The bibliometric analysis conducted in this study provided a detailed and systematic overview of how the international scientific literature has addressed the relationship between infrastructure and rural development over the past three decades, helping us understand what topics are most studied, how ideas are connected, and where research is heading. The results reveal the presence of three main thematic clusters: (1) the socio-political dimensions of rural infrastructure, (2) sustainable transformation and rural development and (3) economic performance and public infrastructure. These clusters reflect not only the diversity of perspectives in the literature but also the interdependence of economic, institutional and social factors in the rural development process. The terms "rural development" and "rural infrastructure" occupy central positions in the network, reinforcing the idea that infrastructure is a key lever in transforming rural areas. The international contributions identified underline the global nature of concerns regarding rural infrastructure, with significant involvement from countries such as China, the United States and Romania. However, the relatively low level of transnational collaboration suggests there is considerable room for improvement in international academic cooperation.

This study contributes to the systematization of existing knowledge and the identification of future research directions, including the deepening of analysis on digital and green

infrastructure in rural areas, the integration of qualitative methods into bibliometric studies for deeper contextual understanding and the expansion of investigations into public policies that support integrated rural development. While the analysis provides valuable insights, it is based solely on patterns observed in the academic literature. As such, it does not capture the full complexity of real-world policy implementation, nor the diverse local contexts in which rural development unfolds. Future research could address these aspects by combining bibliometric methods with case studies, interviews or policy evaluations and by exploring the evolution of these concepts over time. Despite these limitations, the current approach remains useful because it offers a structured overview of how scientific thinking has evolved in this domain. It can help researchers identify emerging areas of interest and support decision-makers in designing targeted, evidence-based interventions.

In conclusion, rural infrastructure can no longer be treated as a purely technical component but must be understood as a fundamental pillar of balanced territorial development, social cohesion and long-term sustainability. Interdisciplinary and collaborative approaches are therefore essential for designing effective policies and interventions that are adapted to the complex realities of the contemporary rural environment. The insights revealed by this study can guide policymakers in prioritizing infrastructure investments that contribute not only to economic growth, but also to inclusive, sustainable rural development.

Conflict of interests

The authors declare no conflict of interest.

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