*Journal of Infrastructure, Policy and Development* 2024, 8(7), 6041.
https://doi.org/10.24294/jipd.v8i7.6041

Article

# Perspectives on project finance and renewable energy infrastructure research

**Santiago Gómez-Valencia[1], Juan David Gonzalez-Ruiz[1,*], Nini-Johana Marín-Rodriguez[2]**

[1] Departamento de Economía, Facultad de Ciencias Humanas y Económicas, Grupo de Investigación en Finanzas y Sostenibilidad, Universidad Nacional de Colombia, Medellín 050034, Colombia
[2] Grupo de Investigación en Ingeniería Financiera GINIF, Programa de Ingeniería Financiera, Facultad de Ingenierías, Universidad de Medellín, Medellín 050026, Colombia
*** Corresponding author:** Juan David Gonzalez-Ruiz, jdgonza3@unal.edu.co

**CITATION**

Gómez-Valencia S, Gonzalez-Ruiz JD, Marín-Rodriguez NJ. (2024). Perspectives on project finance and renewable energy infrastructure research. Journal of Infrastructure, Policy and Development. 8(7): 6041. https://doi.org/10.24294/jipd.v8i7.6041

**ARTICLE INFO**

Received: 25 April 2024
Accepted: 30 May 2024
Available online: 26 July 2024



**Abstract:** This study analyzes the studies on project finance (PF) and renewable energy (RE) arena, employing a comprehensive scientometric analysis to illuminate the current research landscape, identify prominent scholars, and uncover emerging trends. Encompassing several analyses, we have charted the evolution of this domain from 1993 to March 2024 and showed the way for further research. We analyzed 80 studies selected from several databases by means scientometric tools. Despite decent citation rates, research in this relatively young field is surprisingly scarce. While geographically diverse, research leadership stems from the UK, USA, Australia, and Germany. Interestingly, a significant portion of the studies originates from broad energy and sustainability areas, highlighting a potential knowledge gap in finance and economics areas. Additionally, the prevalence of case studies points to a strong connection between theory and practice. The research also revealed prominent topics like the interplay between PF and RE, various renewable resources, infrastructure development, financial considerations, risk management, among others. While many themes exist, areas like technological advancements, diverse cost approaches, valuation methodologies, and policy considerations remain underexplored. Other results unveiled an unexpected finding: limited evidence of large-scale collaborations, with individual or small-group research efforts currently dominating the field. However, existing collaborative networks promise future advancements through the emergence of more formalized research groups, which can perform future research endeavors with a wide spectrum of unexplored topics.

**Keywords:** project finance; renewable energy; infrastructure; financing; scientometric analysis

## 1. Introduction

Despite the recent global energy sector emissions increase after the COVID-19 pandemic, positive signs are on the horizon. The International Energy Agency (IEA) (2024) forecasts a decline in emissions in the coming years, potentially due to growing investments in renewable energy infrastructure (RE). This positive outlook aligns with the urgent need to address the escalating global demand for energy, which is projected to accelerate to an average of 3.4% from 2024 through 2026 (IEA, 2024). To achieve this, advancing RE infrastructure and utilizing financing mechanisms like project finance (PF) and green bonds are crucial (Benavides-Franco et al., 2023; González-Ruiz et al., 2023). This focus on clean energy solutions will be essential for achieving the Sustainable Development Goals (SDGs), particularly the seventh, which is focused on ensuring access to affordable and clean energy for all.

The energy transition that the world is facing from fossil fuel-based generation to renewable energy resources entails the availability of extensive and high capital investments for developing and maintaining infrastructure. Indeed, RE investments surged to $623 billion in 2023, marking an 8% increase from 2022, according to the latest Bloomberg NEF's (2024) report. Nonetheless, Global Infrastructure Hub (2018) data projected a $5.6 trillion investment gap in energy infrastructure by 2040, considering this sector's achievement SDGs. In this scenario, the need for capital and infrastructure investment remains substantial and shows no signs of abating.

As one of the most essential financial strategies for developing infrastructure systems, PF plays a pivotal role (Gonzalez-Ruiz et al., 2019), particularly in RE infrastructure. According to Gatti (2018), much of the existing literature that tried to define PF converges on a key distinction: project success takes center stage. Unlike conventional financing, PF does not prioritize the financial health, or the assets the project's sponsor offers as collateral. Instead, the project itself stands on its own merit. Approval depends on the project's demonstrated ability to generate cash flow sufficient to repay loans and compensate investors for the level of risk involved.

One of its key strengths is minimizing risks and agency costs associated with complex contracting schemes (Benavides-Franco et al., 2023). However, PF also involves higher transaction costs compared to traditional corporate finance (CF). In addition, while CF relies on a firm's existing assets and cash flow to secure loans for new projects (Gatti, 2018; Steffen, 2018), PF prioritizes the project's performance, demanding detailed examination of cash flow projections and costs. This focus on project-specific risk can lead to higher upfront costs associated with technical, commercial, and legal advisors, potentially reaching 5%–10% of the project value (Steffen, 2018).

Despite the scarcity of studies, research on the relationship between PF and RE infrastructure has grown recently. However, this field of study is in a relative developing phase since the first discussions about it can be found a few decades ago (Jr. Middleton and McBurney, 1993; Mills, 1993) and includes analysis from different perspectives. For instance, several studies addressed concerns of PF in the development of RE infrastructure, bringing analysis of the risk's effects, risk assessment, and risk management (Agrawal, 2012; Baker, 2015; Bature et al., 2018; Böttcher, 2020; Braeckman et al., 2022; In et al., 2022; Spasenic et al., 2022a, 2022b). Another aspect of PF in RE infrastructure explored by the literature is the cost of capital, which is one of the key variables determining the feasibility of investment in RE infrastructure (Gohdes et al., 2022). It is also important to highlight the significant number of cases of study in different markets to approach this field of knowledge, namely, wind (Kann, 2009; May, 2017; Rickman et al., 2022; Tseng et al., 2017) and solar (Barroco and Herrera, 2019; In et al., 2022; Kayser, 2016; Lundan and Leymann, 2021; Rafique et al., 2018; Vázquez-Vázquez et al., 2021). This phenomenon entails a strong relationship between theory and practice, bridging the gap between theoretical concepts and practical application.

In other matters, to the best of our knowledge, the relationship between PF and RE is unexplored in the existing body of literature. This oversight is particularly noteworthy given the historical use of PF in the power production sector itself (Gatti, 2018). This prior application suggests PF's potential relationship with the RE sector.

Consequently, there is a lack of research analyzing the current state-of-the-art in this arena. Hence, this study aims at analyzing the relationships between PF and RE infrastructure employing a novel approach, that leverages scientometrics and network analysis techniques, specifically VOSviewer (Jan van Eck and Waltman, 2020) and Bibliometrix tools (Aria and Cuccurullo, 2017). Building on the issues identified previously, the following research questions (RQs) guide this study:

First, we will explore the evolution, productivity, and impact within the PF and RE arena. This exploration encompasses the collaboration patterns, ultimately revealing its key contributions over time. To achieve this objective, we address the following questions:

RQ 1: What is the state-of-the-art in PF and RE arena?

RQ 2: What are the leading studies on PF and RE infrastructure? Are they theoretical or practical approaches?

Second, we will explore the main themes within PF and RE domain. This will involve discussing the emergence and growth of trending topics within this field. By exploring these themes, we aim to uncover potential improvements in both practical applications and academic research:

RQ 3: What are the trending topics in the PF and RE infrastructure arena?

RQ 4: What are the knowledge gaps and further research directions in the PF and RE arena?

Third, we will analyze the leading researchers and cluster collaborative efforts. This analysis will focus on joint research endeavors to identify the most prominent in this domain. Therefore, we address the following question:

RQ 5: Who are the leading researchers in the PF and RE arena?

This study significantly contributes to the existing literature from both practical and academic perspectives. It is a leading study integrating advanced scientometric techniques VOSviewer and Bibliometrix as well as the most reputable databases, Scopus and Web of Science, to analyze the importance of the relationship between PF and RE infrastructure. The reviewed literature lacks applications of scientometric tools to perform a comprehensive analysis. Several studies have explored the connection between PF and RE using both theoretical and practical lenses (Benavides-Franco et al., 2023; Böttcher, 2020; Mills, 1993; Mohamadi, 2021; Srivastava, 2023; Steffen, 2018). These analyses often drew on case studies to support their findings. Notably, Kayser (2013) utilized a commented bibliography approach, structuring the literature review of PF around four key research areas, including RE, and Spasenic et al. (2022) provided research of the financing of projects of RE through a scientometric overview, which used WoS database, employing tools like VOSviewer. Indeed, Spasenic et al.'s (2022) study indicates that further research should consider using other databases and applying wider scientometric methodologies, for which the present study closes this knowledge gap.

These contributions enable the identification of further research opportunities through network mapping and thematic cluster reviews, facilitating the exploration of emerging themes empirically and theoretically. This study presents a novel approach using scientometric techniques to explore a wider body of knowledge on PF and RE infrastructure that expands the knowledge frontier and, more importantly, it serves as a catalyst for the scientific community to expand the knowledge frontier on the subject.

Under this premise, the findings of this study contribute to understanding current trends in this field and lay the groundwork for further research. Also, addressing the relationship between PF and RE infrastructure is going to play a pivotal role in designing solutions for public and private interests, enabling a just energetic transition as the SDG 7th claims to ensure access to affordable, reliable, sustainable, and modern energy for all.

The rest of this article is structured as follows. Section 2 outlines the research methodology. Section 3 presents the scientometric analysis and its corresponding results, offering insights into PF and RE arena guided by the established RQs. Section 4 provides a comprehensive summary and discussion of the scientometric findings in relation to the accomplishment of the RQs. Finally, section 5 concludes the paper with key takeaways and potential future research directions.

## 2. Methodology

This study employs a comprehensive scientometric review methodology to analyze the evolution of the PF and RE landscape. As Haghani (2023) defines it, a scientometric review constitutes a wide-ranging analysis of scholarly publications. This approach primarily utilizes quantitative techniques to investigate scientific dynamics, structure, and impact within a specific field or topic. The analysis includes evaluating patterns, citation networks, co-authorship trends, and research productivity. This multifaceted analysis aims to reveal emerging trends, identify influential research contributions, and understand knowledge body evolution within a particular academic domain (Gonzalez-Ruiz et al., 2024).

### 2.1. Data acquisition and refinement

To ensure the highest quality and comprehensiveness, data were gathered from Scopus and Web of Science (WoS) databases, both widely recognized for their exceptional academic and scientific reputations. Recognizing the relatively emerging stage of development within the PF and RE arena, a tailored search equation was constructed ("project finance" and "renewable energy"). The term "project financing" was deliberately excluded due to its frequent use in a broader context encompassing various project-related financial mechanisms. The search timeframe extended up to March 2024, encompassing both Scopus and WoS databases. This initial search yielded 76 and 52 studies from Scopus and WoS, respectively. Then, 67 and 35 studies were manually selected, respectively, excluding those articles that did not provided a clear relationship between PF and RE. For example, several articles were excluded because they focused merely in one of the two areas.

To create a unified and non-redundant dataset, the Bibliometrix R-package was employed to merge the results from both searches into a single database. This process effectively identified and eliminated 22 duplicate studies, resulting in a refined dataset of 80 unique publications. All included studies were downloaded and compiled within Mendeley, facilitating further analysis and citation management.

Databases were picked according to the criteria provided by Öztürk (2021), which included aspects such as accessibility, journal impact factors, availability of data in a format compatible with scientometric analysis software, and number of

documents, among others. Web of Science (WoS) and Scopus were selected based on their established standing within the academic community as the best two bibliographic databases (Öztürk et al., 2024; Pranckutė, 2021), and considering that our work requires comprehensive databases to perform scientometric analysis. WoS offers a widely recognized and comprehensive database encompassing a vast collection of top-tier journals distinguished by their high impact factors (Kumari and Singh, 2023). Notably, WoS ranks among the most popular choices for scientometric analysis due to its user-friendly interface and advanced search functionalities, including the "KeyWords Plus" feature that facilitates retrieving a broader range of relevant studies (Korom, 2019). As the world's largest research database, Scopus boasts extensive coverage across a diverse spectrum of academic disciplines (Pranckutė, 2021; Zhu and Liu, 2020). This includes a meticulously curated selection of journals specifically focused on the renewable energy and finance arena, aligning perfectly with the research focus of this study.

## 2.2. Scientometric procedures

This study leverages a comprehensive suite of scientometric techniques to analyze the evolution of the PF and RE research landscape. These techniques encompass examining scientific production, publication sources, seminal studies, authorship patterns, and research clusters, among others. By employing these methods, this study includes:

- Identification of key actors and intellectual leaders: leading researchers, research institutions, contributing countries, and the most prominent scholarly sources within the field.
- Delineation of seminal studies: to identify the foundational and highly influential publications that have shaped the research trajectory in the PF and RE landscape.
- Discerning research trends: Through rigorous analysis, uncover and elucidate the prevailing research trends within this domain.

The findings derived from the scientometric analysis are further enhanced by applying visualization tools. VOSviewer (Jan van Eck and Waltman, 2020) and Bibliometrix for R-package (Aria and Cuccurullo, 2017) serve as the primary software employed for visually representing the research landscape. Thus, recognizing the value of science mapping in deconstructing and visualizing the intellectual structure of a field, this study incorporates a variety of techniques that were approached latterly by Gonzalez et al. (2024). These techniques include co-authorship analysis, co-citation analysis, bibliographic coupling, co-occurrence of keyword analysis, and citation analysis, among others. **Figure 1** illustrates the comprehensive literature search strategy employed to conduct this study.

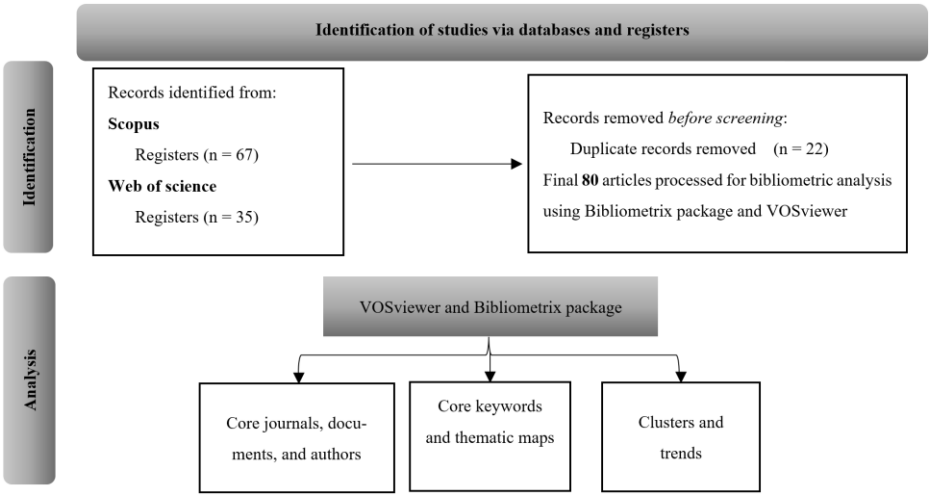



**Figure 1.** Literature search strategy.
Source: Author's own research using the Bibliometrix R package, as well as Scopus and WoS databases.

## 3. Scientometric analysis

### 3.1. General information

In the realm of sustainable investing and lending, the relationship between private finance (PF) and renewable energy (RE) infrastructure has garnered significant attention from both professional and academic circles in recent years. This growing interest has been fueled by 80 studies co-authored by 166 researchers, which have provided valuable insights into the PF and RE infrastructure arena. **Table 1** summarizes the leading research on the PF and RE infrastructure arena.

**Table 1.** Summary of the studies (Source: Authors' own research using the Bibliometrix tool, as well as Scopus and WoS databases).

| Description | Results | Description | Results |
|---|---|---|---|
| **Main information** | | **Study types (continued)** | |
| Timespan | 1993: March 2024 | Editorial material | 1 |
| Sources (journals, books, etc.) | 63 | Review | 4 |
| Studies | 80 | **Study contents** | |
| Annual growth rate % | −2.21% | KeyWords Plus | 413 |
| Study average age | 7.81 | Author keywords | 251 |
| Average citations per study | 12.47 | **Authors** | |
| References | 1596 | Authors | 166 |
| **Study types** | | Authors of single-authored docs | 30 |
| Article | 55 | **Authors collaboration** | |
| Article; early access | 0 | Single-authored docs | 32 |
| Books/chapters | 4/7 | Co-Authors per doc | 2.34 |
| Conference papers | 9 | International co-authorships % | 11.25% |

The average age and citations per study are 7.81 and 12.47, respectively. These figures underscore that most research has been conducted within the last two decades

and has substantially contributed to the field. However, it is worth noting that the field is not experiencing significant growth, as evidenced by an annual growth rate of −2.21%. This deceleration is likely partially due to the inclusion of data from the current year (2024), as research on this topic is still ongoing, and new publications are expected throughout the year. Also, this deceleration highlights a potential gap and calls for increased research attention in this area. Articles constitute the most prevalent form of publication, accounting for 55%. Additionally, the extensive use of KeyWords Plus (413) and author keywords (252) suggests that studies in the PF and RE infrastructure arena are interconnected with various other branches of knowledge.

### 3.1.1. Annual scientific publication

Although the first publication in this arena dates back to 1993, with several studies mentioning both PF and RE, the area emerged in 2012 with the study titled "Risk mitigation strategies for renewable energy project financing" (Agrawal, 2012). This article argued for project finance as the preferred financing mechanism for RE projects due to its effectiveness in managing the inherent risks. The research comprehensively addressed the entire spectrum of risk factors and outlined the corresponding mitigation strategies within this growing field.

**Figure 2** shows that a significant increase in scientific production related to PF and RE infrastructure has occurred since then. Thus, the increasing interest in the relationship between PF and RE infrastructure within the academic community has been notable. However, as noted earlier, this interest may not be sufficient. Consequently, as depicted in **Table 1,** studies published in this field have shown a negative annual growth rate of −2.21%, including 2024 data. Considering only the years up to and including 2023, the annual growth rate was 3.1%, which is still relatively low. As of March 2024, 80 studies have been published in total. It is important to highlight that from 2012 to March 2024, the number of studies published was 65, which accounts for 81% of the total published.

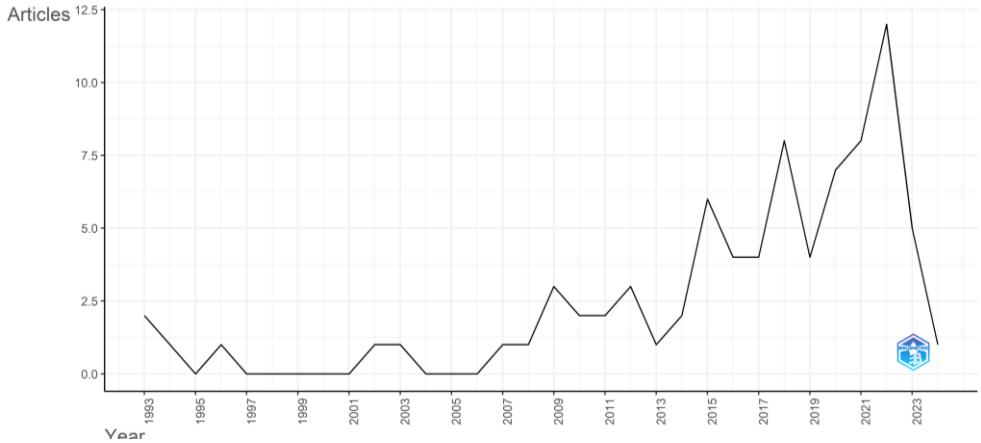



**Figure 2.** Annual scientific production.

Source: Authors' own research using the Bibliometrix tool, as well as Scopus and WoS databases.

This surge in publications likely coincided with the momentum around the previous decade's dynamics around the construction and development of the SDGs, which started in 2012. During this time, the PF and RE infrastructure field had to become highly relevant due to its connection to SDG 7th and the need to mobilize

capital for RE projects. PF emerged as a powerful mechanism for achieving this goal.

For example, Barroco and Herrera (2019) conducted a study on the determinants of financing method choice between PF and CF, which leveraged the parent company's assets. The analysis focused on the feed-in tariff (FIT) as a key factor influencing this decision. The Philippines served as a case study to explore this dynamic within a developing country context. Remarkably, despite the approval of the Renewable Energy Law (RE Law) in 2008, RE capacity increased while its share in the overall energy mix decreased. This highlights the need to strengthen RE capabilities through improved financing and capital mobilization using project finance.

Also, Steffen (2018) explored the significance of project finance for renewable energy projects in investment-grade countries, exploring the underlying motivations for its use. His findings revealed a crucial role for project finance in renewable energy investments, particularly in this case study with exceptionally low investment risks. Project finance is much more critical for renewables within this context than fossil fuel-based power plants. This highlights the interconnectedness of this knowledge field with the energy transition that has gained momentum in recent years.

On the other hand, since the beginning of this decade, a significant increase has been observed in published studies (26) on PF and RE arena. Notably, a large portion of these studies covered a selection of topics, including decarbonization and the transition to a net zero economy, strengthening RE capacities, the need for financing mechanisms such as PF with endeavored risk analysis and other characteristics, and policy implications (Braeckman et al., 2022; Baker, 2022; Lundan and Leymann, 2021; Mohamadi, 2021; Srivastava, 2023).

### 3.1.2. Most relevant journals

**Figure 3** presents an analysis of the most influential journals based on the number of published studies within the relationship between PF and RE arena. The analysis reveals a distinct preference among researchers to publish their work in journals primarily focused on the energy domain, with a marginal representation from economics and finance. Consequently, journals such as Energy Economics, Energy Policy, and Applied Energy emerge as the most prominent venues for research in this area.

Energy Economics stands out with five publications examining various aspects of PF and RE infrastructure. These studies mainly encompass the need for policy interventions in Germany that aim to incentivize the adoption of moderately more system-friendly wind power technologies (May, 2017), the crucial role of PF in facilitating RE projects within developed countries characterized by low-risk profiles (Steffen, 2018), and how long-term Power Purchase Agreements (PPAs) with creditworthy counterparties (investment-grade) are essential for securing PF for RE projects in Australia (Gohdes et al., 2022).

The Energy Policy journal features five publications that delve into the intersection of PF and the US energy sector, with a particular focus on policy frameworks, wind power generation, and the application of PF structures within this industry (Kahn, 1996), Two case studies which explore the role of financial institutions' policies in reducing electricity production costs through the mobilization

of private investments via PF models that leverage discounted cash flow analysis (Frisari and Stadelmann, 2015), and a case study from the Philippines which address the factors influencing the choice between PF and CF for project financing (Barroco and Herrera, 2019).

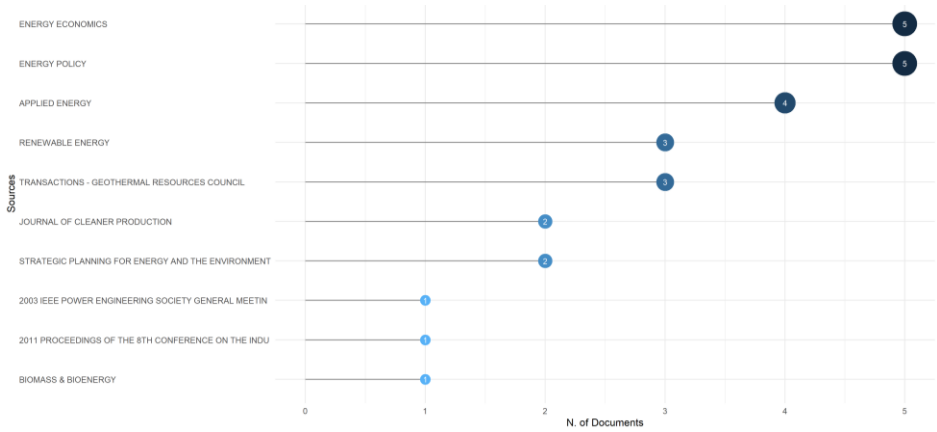



**Figure 3.** Most relevant journals.
(Source: Authors' own research using the Bibliometrix tool, as well as Scopus and WoS databases).

The Applied Energy journal, with four published studies, primarily focuses on the financial role assumed by the Chinese government within the renewable energy (RE) sector, particularly in a context characterized by a multitude of risk factors (Kayser, 2016), the nexus between PF and wind resource assessment, alongside the trade-off between development expenditure and financing costs (Mora et al., 2019), and the trends in technology and cost associated with land-based wind energy across six countries (Denmark, Germany, Ireland, Norway, Sweden, and the United States). A decrease in PF costs is highlighted by reductions in the international cost of debt and advancements in wind energy technology (Duffy et al., 2020).

**Figure 3** shows a noticeable trend in the increasing integration of financial considerations within top-tier energy-focused journals. In contrast, leading finance and economics journals do not reciprocate this cross-disciplinary approach. To bridge the gap between these two fields and address the relationship between PF and RE, top-tier finance and economics journals should encourage and publish more studies that explore this nexus.

### 3.1.3. Most cited sources

This research stage analyzes fifty publication sources encompassing journals, books, book chapters, and conference proceedings. Research impact assessments are based on the h-index, a metric proposed and defined by Hirsch (2005). The h-index reflects the number of a researcher's publications cited at least *h* times. This research utilizes the *h*-index to characterize the scientific output of researchers within the project finance PF and RE field, drawing upon a corpus of eighty published studies in this domain. **Table 2** presents the primary publication sources within PF and RE domains. As can be seen, Applied Energy and Energy Policy are the leading high-quality journals with a remarkable 4 *h*-index, followed by Energy Economics, and Renewable Energy with a 3 *h*-index. Notably, all four of these prominent journals are classified as Q1 by Scimago in distinct categories, these journals also contribute to

21.25% of the total published papers in the field, as shown in **Table 2**. While the research exhibits dissemination across various journals, a degree of concentration is evident within the four journals mentioned above. Furthermore, these findings emphasize the significance of ensuring widespread access to scientific knowledge, thus empowering researchers to leverage the collective expertise within the field.

**Table 2.** Top highly cited sources.

| Source | *h* index | *g* index | Total citations | Number publications | Top category Scimago | Date of first publication |
|---|---|---|---|---|---|---|
| Applied Energy | 4 | 4 | 98 | 4 | Q1 | 2016 |
| Energy Policy | 4 | 5 | 163 | 5 | Q1 | 1996 |
| Energy Economics | 3 | 5 | 202 | 5 | Q1 | 2017 |
| Renewable Energy | 3 | 3 | 56 | 3 | Q1 | 1994 |
| Journal of Cleaner Production | 2 | 2 | 22 | 2 | Q1 | 2011 |
| Geoforum | 1 | 1 | 86 | 1 | Q1 | 2015 |
| Infrastructure as an Asset Class: Investment Strategy, Sustainability, Project Finance and PPP | 1 | 1 | 63 | 1 | N/A | 2016 |
| Renewable and Sustainable Energy Reviews | 1 | 1 | 14 | 1 | Q1 | 2022 |
| Environment and Planning E: Nature and Space | 1 | 1 | 12 | 1 | Q1 | 2022 |
| Biomass and Bioenergy | 1 | 1 | 14 | 1 | Q2 | 2015 |

(Source: Authors' own research using the Bibliometrix tool).

Interestingly, among the ten most frequently cited sources, only two (including the book) fall within the finance or economics domain. This observation highlights the prominence of research published in journals categorized within Scimago's Q1 and Q2 quartiles, encompassing diverse categories such as energy (miscellaneous), renewable energy, sustainability and the environment, policy and law, economics, econometrics, and finance, among others.

Furthermore, it is noteworthy that journals constitute the vast majority of these highly cited sources, with just a single book included within the top ten. These findings suggest that the knowledge base surrounding PF and RE, which contributes to the achievement of SDG 7th, is being actively explored by researchers from a broad spectrum of energy and sustainability-related areas, with a comparatively limited contribution from the fields of finance and economics. This underscores the growing need for further studies on the relationship between PF and RE, particularly within interdisciplinary collaboration. As mentioned, this domain presents a significant opportunity for future research endeavors.

## 3.2. Core researchers

### 3.2.1. Most relevant researchers

**Figure 4** presents the most prominent researchers contributing significantly to PF and RE infrastructure research. The figure leverages bubble size to visually represent the number of publications authored by each scholar. Color intensity is employed as an indicator of the average annual citation rate, calculated by dividing

the total number of citations received by the number of years elapsed since publication up to 2024.

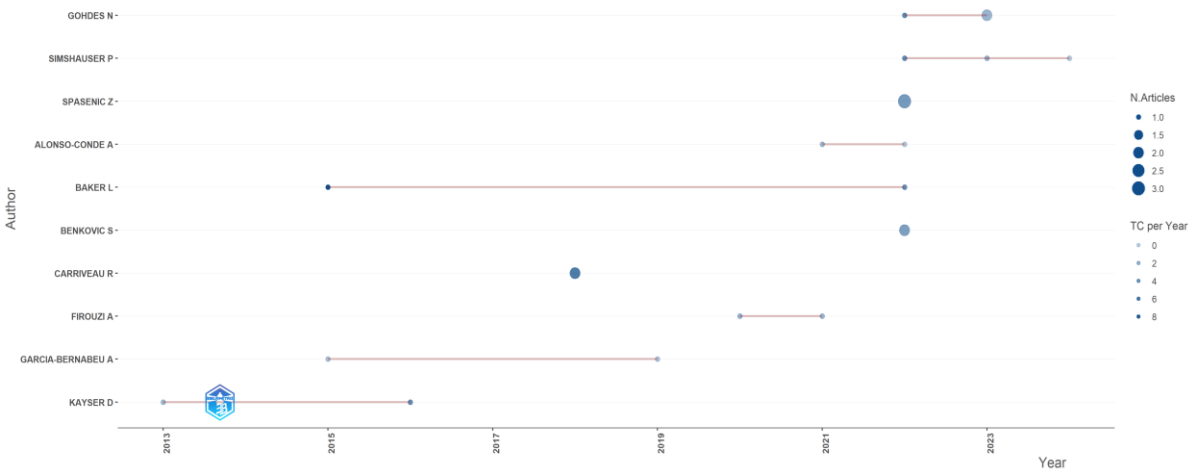



**Figure 4.** Most relevant researchers by production over time.
Source: Authors' own research using Bibliometrix tool, as well as Scopus and WoS databases.

This analysis reveals that the most prominent researchers in this domain initiated their careers in PF and RE within the past decade. This observation reinforces the notion that PF and RE represent a growing field of knowledge with significant potential for further exploration and research. Mainly, Gohdes et al. (2022) emerged as some of the most prolific researchers in this arena, with three studies published, which is remarkable since they started their careers in 2022.

The main interests that these researchers endeavored to approach are related to various kind of topics within the relationship of PF and RE infrastructure: cost of capital forecasts for solar energy projects in Spain, particularly within the context of traditional PF structures (Vázquez-Vázquez et al., 2021), policy considerations for RE deployment in Australia, emphasizing the pivotal role of PF as the dominant financing mechanism in that nation, especially in light of the recent war in Ukraine and its resulting energy market crisis (Gohdes et al., 2023), and the leverage of a case study to conduct a risk assessment for a small hydropower plant financed through PF in Serbia and offer valuable insights for credit risk managers evaluating PF loan requests (Spasenic et al., 2022b). Similarly, Garcia-Bernabeu et al. (2019) employ a multicriteria financial risk management and assessment approach to select RE projects suitable for commercial bank funding through PF schemes. Firouzi et al. (2021) propose a novel stochastic framework for optimizing the debt service schedule concerning the project company's probability of default using a PF scheme, an approach associated with risk-based optimization. Finally, Spasenic et al. (2022) make a pioneering contribution by developing a bibliometric analysis to address the relationship between PF and RE infrastructure.

The researchers which were examined at this stage exhibit a high degree of coherence with the findings presented in the preceding section. For instance, the categorization of the leading journals aligns with the research focus identified earlier. Furthermore, the authors of these reviewed studies have grappled with similar research problems.

### 3.2.2. Most relevant researchers' affiliation

**Figure 5** illustrates the leading institutions contributing substantially to PF and RE research. The ranking is based on the number of published studies, with the following institutions emerging as the top 10 contributors. Griffith University, ETH Zurich, University of Delaware, University of Belgrade, CanmetEnergy, University of Cambridge, University of Minnesota Twin Cities, Islamic Azad University, Swiss Federal Institutes of Technology Domain, University of Sussex, and University of Windsor.

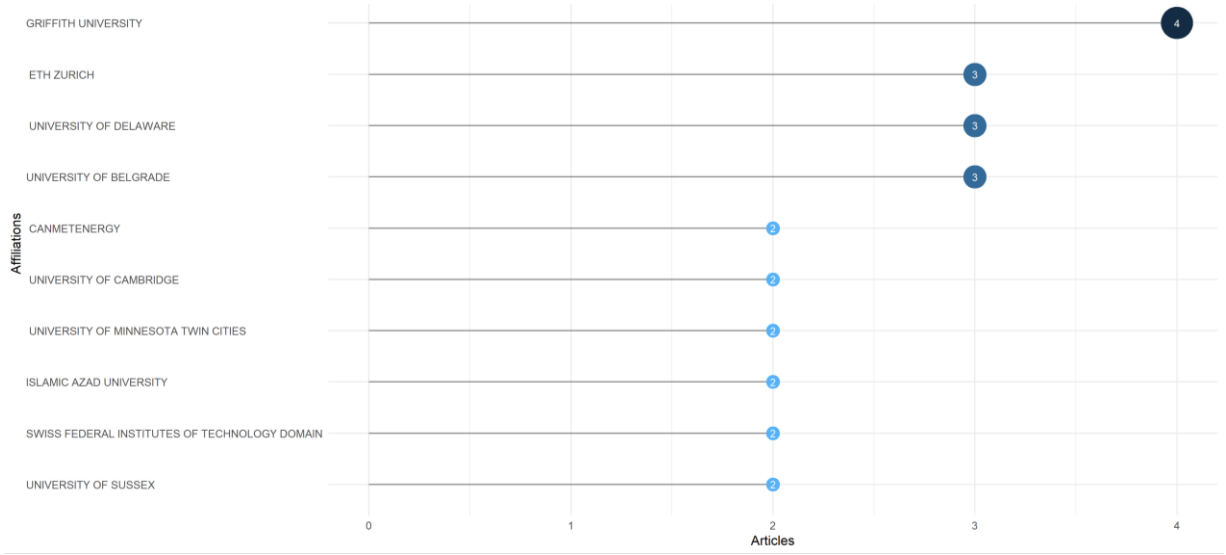
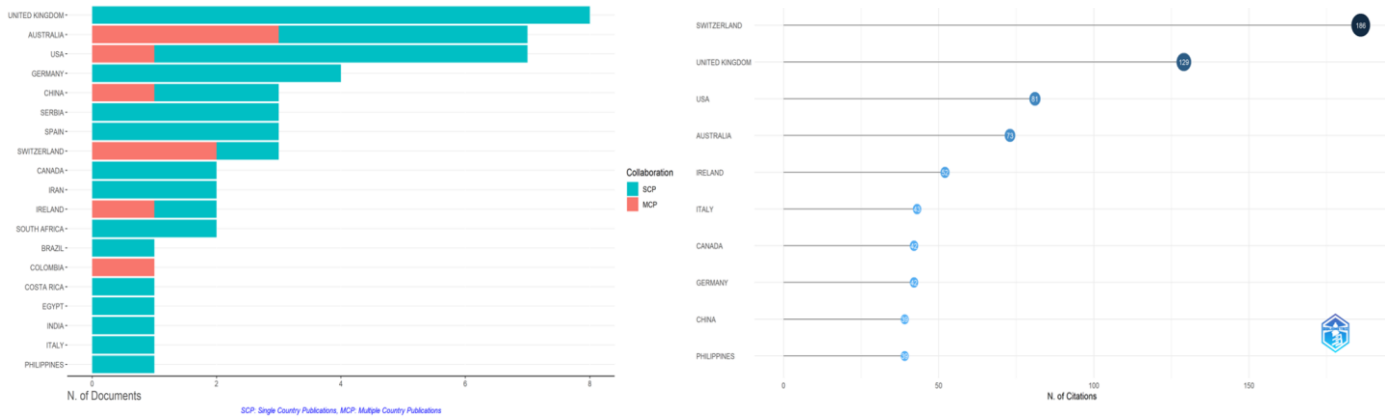



**Figure 5.** Most relevant affiliations.
Source: Authors' own research using Bibliometrix tool, as well as Scopus and WoS databases.

**Figure 5** reveals that the top four institutions hold a significant position in this research domain. This suggests a potential specialization within these institutions, fostering contributions that explore PF and RE nexus from diverse approaches. Notably, Griffith University exhibits a high volume of publications both independently and in collaboration with other institutions, such as the University of Cambridge. This collaborative activity lends credence to establishing dedicated research groups within these institutions. Furthermore, the observed inter-institutional collaboration undoubtedly contributes to enhanced academic publication metrics.

### 3.2.3. Researchers' country analysis

**Figure 6a** depicts the countries of corresponding authors significantly contributing to the PF and RE arena research. Remarkably, the United Kingdom, Australia, the USA, and Germany emerge as the most relevant countries, measured by the number of published studies. In general, every country has its publications spread across several universities. Related to the studies carried out in the UK, they are based on risk issues across PF and RE arena. However, as measured by the number of citations, the highest-impact publications are in Switzerland, the UK, the USA, and Australia.




**(a)** **(b)**

**Figure 6.** Author's country analysis of correspondence. **(a)** corresponding research's countries; **(b)** most cited countries.

(Source: Authors' own research using Bibliometrix tool, as well as Scopus and WoS databases).

A notable characteristic of this research field is the tendency for studies focused on a particular country to be conducted solely by researchers from that nation. For instance, all studies in the UK have been addressed by domestic researchers. This observation suggests a potential lack of international collaboration within this domain, and the nature of the reviewed research could justify that scarcity. This observed trend can be partially attributed to the unique contextual understanding possessed by native researchers. Their direct and personal familiarity with their home country's infrastructural and economic landscape offers a distinct advantage.

Furthermore, it is important to acknowledge that each nation faces unique risks associated with climatical or geological characteristics, policies, among others, in the PF scenario and RE infrastructure development. However, the number of published works could be significantly increased by fostering cooperation and establishing robust research networks across geographical boundaries. Such collaboration can also enhance research contributions' quality, scope, and relevance.

**Figure 6b** delves into the research landscape by presenting the most cited countries within the PF and RE infrastructure arena. Switzerland emerges as the leading nation with 186 citations, followed by the United Kingdom (129), the United States (81), and Australia (73). These findings offer valuable insights into these countries' research focus on PF and RE infrastructure. Notably, they demonstrate high coherence with the results presented in the preceding sections. For instance, the significant presence of leading institutions from Switzerland within the PF and RE field aligns with this observation. The high citation counts garnered by these countries indicate the substantial influence and recognition accorded to their research within the academic community. This recognition underscores these nations' significant contributions to advancing knowledge in PF and RE infrastructure field.

**Figure 6a,b** provide valuable insights into the distribution of research output and citation impact across countries within the PF and RE arena. Analyzing these patterns is critical for several reasons. First, it allows for the identification of leading contributors to the field. Second, it facilitates the fostering of collaborative research efforts across geographical boundaries. Finally, understanding these patterns enables

the recognition of highly influential research outputs that significantly contribute to advancing knowledge in the nexus between PF and RE infrastructure.

## 3.3. Core studies

### 3.3.1. Most influential studies

Within the domain of scholarly research, citation analysis stands as a pivotal methodology. This approach is premised on the notion that citations are powerful indicators of a study's impact (Culnan, 1987). By meticulously examining citation patterns, citation analysis offers a valuable tool for evaluating the influence and significance of academic research. It provides researchers with a quantitative measure of recognition within the academic community, fostering a deeper understanding of the dissemination and reception of their contributions. This introspective examination of citations illuminates the most impactful research and unveils the interconnectedness of ideas. It facilitates the construction of a multifaceted web of knowledge that transcends disciplinary boundaries and empowers intellectual progress. **Table 3** presents the most relevant published documents identified through citation analysis. These works primarily focus on the relationship between PF and RE, exploring finance (risks, costs) approaches through case studies and analyzing relevant policy frameworks.

**Table 3.** Top 10 globally cited studies in the PF and RE arena research.

| | Study | Source | Year | Total citations |
|---|---|---|---|---|
| 1 | Steffen (2018) | Energy Economics | 2018 | 158 |
| 2 | Baker (2015) | Geoforum | 2015 | 86 |
| 3 | Weber et al. (2016) | Infrastructure as an asset class: Investment strategy, sustainability, project finance, and PPP | 2016 | 63 |
| 4 | Kann (2009) | Energy Policy | 2009 | 51 |
| 5 | Frisari and Stadelmann (2015) | Energy Policy | 2015 | 43 |
| 6 | Barroco and Herrera (2019) | Energy Policy | 2019 | 39 |
| 7 | Miller and Carriveau (2018) | Energy Storage | 2018 | 38 |
| 8 | Rafique et al. (2018) | Renewable Energy | 2018 | 38 |
| 9 | Kayser (2016) | Applied Energy | 2016 | 36 |
| 10 | Duffy et al. (2020) | Applied Energy | 2020 | 34 |

Source: Authors' own research using Bibliometrix tool, as well as Scopus and WoS databases.

Regarding the relevance of the study conducted by Steffen (2018) titled "The importance of project finance for renewable energy projects", it highlights PF as a crucial tool for financing RE projects in developed countries with low-risk environments. PF offers distinct advantages to RE projects, such as securing non-recourse debt and mitigating development/operation risks. The growing complexity of RE projects, increased investor risk tolerance, and supportive policies drive the adoption of PF. Understanding these advantages and drivers should guide policymakers and developers in effectively leveraging this financing mechanism. However, further research is encouraged in order to explore how PF can be applied and address challenges in different RE project contexts, particularly in developing

economies. Additionally, the specific advantages and disadvantages of PF will vary depending on the unique characteristics and context of each RE project.

The study conducted by Baker (2015), which is titled "The evolving role of finance in South Africa's renewable energy sector", focused on the growing importance of PF in funding RE projects in South Africa. It might discuss the reasons behind this shift, such as larger and more complex RE infrastructure projects, increased investor interest in the sector, and relevant South African policies. Also, Weber et al.'s (2016) book offers a wealth of critical insights. It not only delves into categorizing diverse organizational models for public-private partnership (PPP) investment but also situates PPP within the broader landscape of infrastructure investment—where RE sector is included—and Kann (2009), in the study titled "Overcoming barriers to wind project finance in Australia" identified how PF had offered a promising avenue for financing wind projects in Australia, despite challenges like high debt costs, perceived risks, and community concerns.

Furthermore, how can these hurdles be addressed through policy and market measures. Barroco and Herrera (2019), Frisari and Stadelmann (2015), as well as Kayser (2016) endeavored similar approaches that were described previously. Noteworthy, case studies are frequently used within the PF and RE infrastructure arena. All of these, which are shown in **Table 3**, have contributed to the evolution of this field of knowledge by shedding light on different topics, each with its own unique characteristics, employing particular lenses and approaches while uncovering potential benefits to developing this growing research area.

For example, the nexus between PF and RE infrastructure can be carried out by research as the developed by Rafique et al. (2018), where the researchers encouraged people and the government in Pakistan to develop zero energy communities through the utilization of RE sources. They aimed to achieve this by conducting a feasibility study based on PF, fuel saving potential, energy production, capacity factor, and reduction of greenhouse gas emissions.

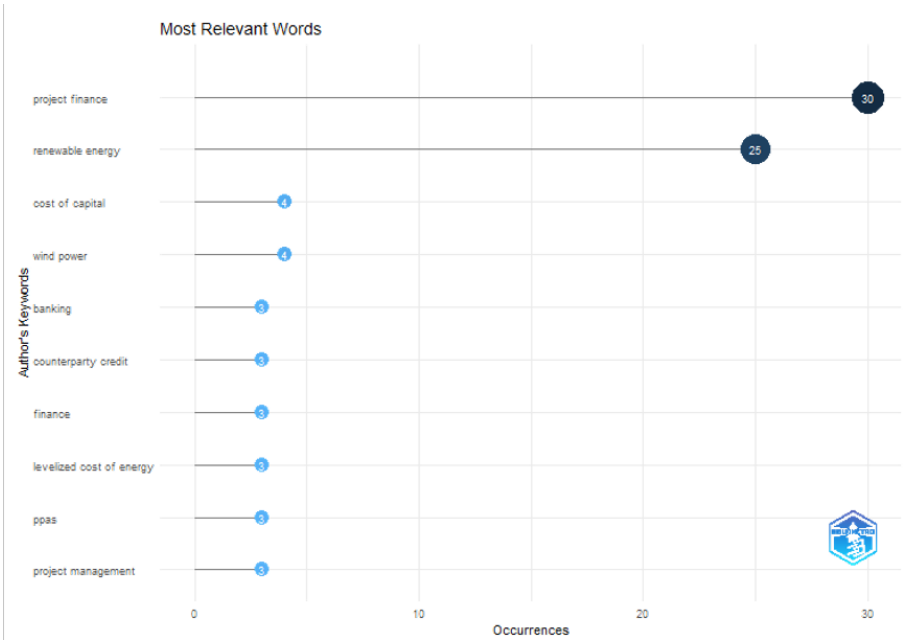
### 3.3.2. Co-occurrence of keywords analysis

Analyzing the keyword's relative importance within the domain PF and RE infrastructure research facilitates a more nuanced and comprehensive understanding of knowledge generation patterns. In this vein, both author's keywords and KeyWords Plus offer valuable insights into individual studies' specific research focus and objectives. By examining these combined keyword clusters, researchers gain valuable perspectives on emerging trends within the field, reflecting the vantage point of the research community.

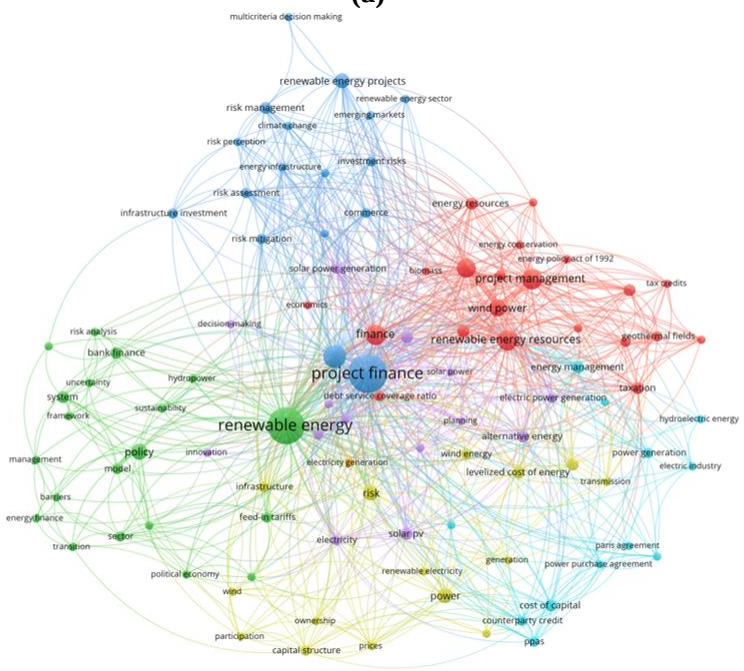
**Figures 7a,b** reinforce the observations made in prior sections. As anticipated, prominent and trending topics within this nascent field of research encompass PF, RE, various RE resources (solar, wind, hydro), infrastructure, finance, risk (management, perception, assessment), sustainability, and policy, among others.

**Figure 7b** further delves into the interconnectedness of these topics, signifying a growing research focus on the linkages between PF and RE with a diverse range of other areas. Given the underdevelopment of PF and RE research, a significant research effort remains necessary to analyze the connections between PF and RE, and related themes.

While nearly all topics have received some attention, with at least one article addressing each, this breadth of coverage should not be misconstrued as a complete exploration of the knowledge frontier. Several topics, such as technological advancements, cost approaches, valuation methodologies, and taxation, remain unexploited within this field. Further research is essential to address this prevalent underdevelopment, requiring a greater volume of scholarly studies dedicated to both prominent and emerging themes.




**(a)**




**(b)**

**Figure 7.** Most frequent keywords. **(a)** author's keywords; **(b)** KeyWords Plus.
Source: Authors' own research using Bibliometrix tool and VOSviewer, as well as Scopus and WoS databases.

### 3.3.3. Thematic map

**Figure 8** leverages a thematic map to categorize research topics within the field using Keywords Plus. This analysis employs a two-dimensional graph considering each topic's centrality and density. Centrality reflects a topic's relative importance within the research field, while density indicates the level of development for that specific topic (Zhang et al., 2022). Bibliometric mapping, the underlying principle of this analysis, illuminates the intellectual, conceptual, and methodological structures of specific disciplines, scientific domains, and research fields.

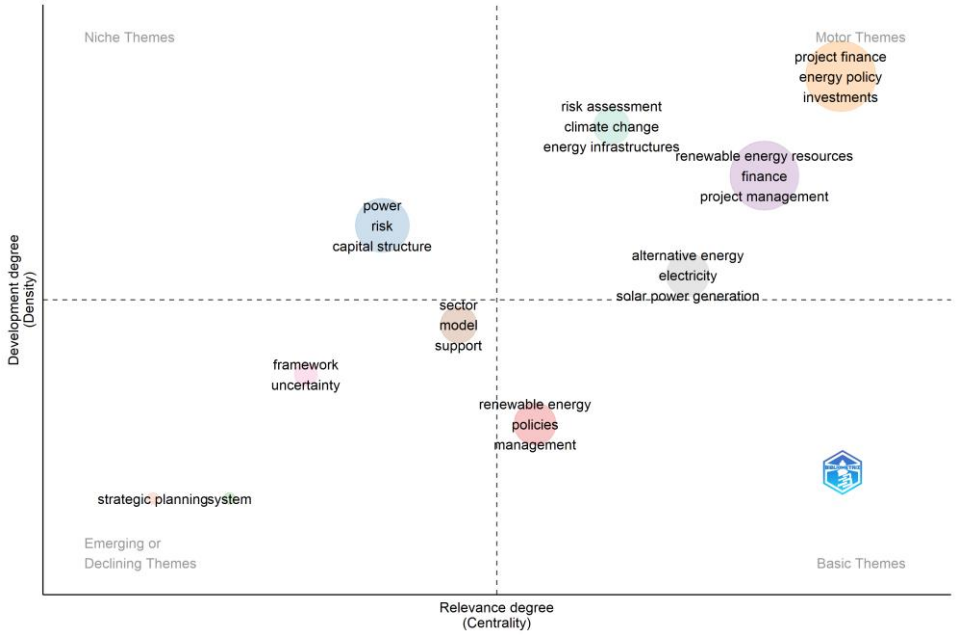



**Figure 8.** Thematic map using KeyWord Plus.

Source: Authors' own research using Bibliometrix tool and VOSviewer, as well as Scopus and WoS databases.

Thus, several themes are shaped based on the keywords of the published studies, as shown in **Figure 8**. The quadrant 1 (motor themes), located on the upper right side, is related to those topics that have relevance, significance, and development in the PF and RE field. This suggests that these topics have become well-developed and constitute foundational pillars of the research field (Zhang et al., 2022). For instance, topics related to PF, RE resources, risk assessment, and climate change, among others, receive particular attention in the research field. While alternative energy, electricity, and solar power generation are also located within this quadrant, their centrality is relatively low. Based on these findings, these topics appear either not yet fully developed or potentially superseded by more encompassing terms (e.g., renewable energy replacing alternative energy).

The quadrant II (niche themes), located in the upper left quadrant, includes strongly developed but isolated topics. Thus, topics such as power, risk and capital structure need to be articulated with others to continue contributing to PF and RE arena's growth. For example, PF and RE, and capital structure are complex and evolving, research on relationships within them can help to expand the knowledge frontier.

On the other side, quadrant III (emerging themes) stands in contrast to topics in quadrant II. Here, research interest appears to be waning over time, or the topics themselves are weakly developed and peripheral to the field. This does not necessarily negate their relevance, especially within a potentially dynamic and rapidly evolving arena. The current study suggests that strategic planning topics could gain renewed relevance within the research domain when approached from a financial and energy-focused perspective.

Finally, quadrant IV (basic themes) encompasses peripheral topics that exhibit high development potential but remain relatively underdeveloped. The thematic map, for instance, identifies renewable energy (RE) and policy as underdeveloped topics, despite their foundational role in supporting other research themes. In summary, the insights presented in **Figure 8** offer valuable guidance to researchers, highlighting the most promising directions for future research. By exploring these topics, researchers can advance their knowledge and deepen their understanding of this interesting research field.

### 3.3.4. Contributions, theories, and trends

Consolidating the literature on PF and RE infrastructure and the previously performed analysis, the main contributions, theories, and trends are indicated below.

The contributions of PF and RE infrastructure arena can be classified into four main areas:

- PF enhanced capital mobilization capabilities: PF plays a pivotal role in mobilizing capital for RE projects, overcoming traditional financing limitations, and facilitating large-scale infrastructure development, which is crucial for achieving SDG 7. Studies by Benavides-Franco et al. (2023) and Steffen (2018) highlight this aspect.
- Bridging the gap between theory and practice: The growing body of research on PF and RE, exemplified by case studies in wind and solar energy across different countries (e.g., Kayser (2016); Rickman et al. (2022); Spasenic et al. (2022a)), demonstrates a robust connection between theoretical concepts and practical applications in the field.
- Risk management and assessment: PF structures effectively address the inherent risks associated with RE projects, as evidenced by Agrawal (2012), Böttcher (2020) and Bature et al. (2018), among other authors. This enables project feasibility and attracts investors.
- Policies' role within PF and RE arena: Policymakers have a pivotal role in the development of a strong RE infrastructure by stimulating the usage of financial mechanisms such as PF, as several researchers demonstrated across different countries with different characteristics (Barroco and Herrera, 2019; Frisari and Stadelmann, 2015; Kahn, 1996; Jr. Middleton and McBurney, 1993; Nickerson et al., 2015).

PF and RE infrastructure arena can be analyzed from the lens of different theories, such as:

- Core principles of PF, including non-recourse debt financing and risk allocation, are fundamental to structuring diverse projects (Gatti, 2018). Studies conducted by Benavides-Franco et al. (2023), Steffen (2018) and Spasenic et al. (2022b),

among others, delve into the application of these principles.

- Risk management frameworks are crucial for evaluating and mitigating risks inherent to RE projects, ensuring project success. For example, Baker (2015) and Bature et al. (2018) explore these topics.

Noticeable trends in PF and RE infrastructure landscape can be classified into three main areas:

- Focus on energetic transition, decarbonization, and net zero economies: The increasing emphasis on decarbonization and transitioning to a net-zero economy drives research on how PF can facilitate RE infrastructure development to achieve these goals (Emodi et al., 2022; Baker, 2022; Nelson, 2020; Rafique et al., 2018).
- Emerging economies, PF, and RE strengthening: Further research is needed to explore how PF can be adapted and applied to RE projects in developing economies with unique risk profiles and financial landscapes. For example, the study conducted in Pakistan by Rafique et al. (2018) is a perfect example of this trend.
- Integration of interdisciplinary considerations: As addressed previously, integrating financial considerations within energy-focused topics is needed within PF and RE landscape. Fostering interdisciplinary collaboration between finance and energy research in the future is fundamental. There is an evident scarcity of financial sources approaching this field of knowledge.

## 3.4. Bibliography coupling

Bibliographic coupling offers a robust and comprehensive approach to analyzing relationships between citing publications. This methodology sheds light on developing knowledge within a research field, mainly focusing on current trends and emerging themes. The core principle lies in identifying clusters of citing publications that converge by referencing a standard set of prior works. These clusters indicate shared intellectual terrain, highlighting a specific field's thematic coherence and interconnectedness (Öztürk et al., 2024). This technique facilitates categorizing studies into cohesive groups that exhibit strong interrelationships, thereby revealing a significant degree of logical correlation within the field (Li et al., 2022). The true power of this method lies in its ability to unveil and elucidate the underlying intellectual connections and thematic associations embedded within the scientific literature. This enables researchers to gain a profound understanding of the intricate interdependencies and thematic coherence that prevail within the field of study (Dwivedi et al., 2023).

### 3.4.1. Co-citation analysis of the studies

To expose and address the interconnected networks between scientific production, co-citation analysis, among others, should be used (Öztürk et al., 2024). This technique facilitates the analysis of the academic structure within scholarly domains. Co-citation network analysis emerges as an invaluable tool for understanding intricate relationships between scholarly works. It empowers researchers to visualize and comprehend the multifaceted interplay of ideas within a field (Shiau et al., 2023). In PF and RE infrastructure research, co-citation network analysis takes center stage,

allowing researchers to map the connections among seminal studies. This approach enables the identification of relationships between different studies, facilitating their categorization and the discovery of research patterns that might otherwise remain elusive.

The findings presented in the co-citation network **Figure 9** demonstrate a high degree of consistency with those outlined in **Table 3**, which identified the ten most cited articles within the field of PF and RE. Notably, Steffen (2018) emerges as a central figure in this domain, with his work being referenced prominently within the network. As discussed in earlier sections 3.1.1., 3.1.2., 3.3.1., and 3.3.4., his contributions have been instrumental in advancing the field.

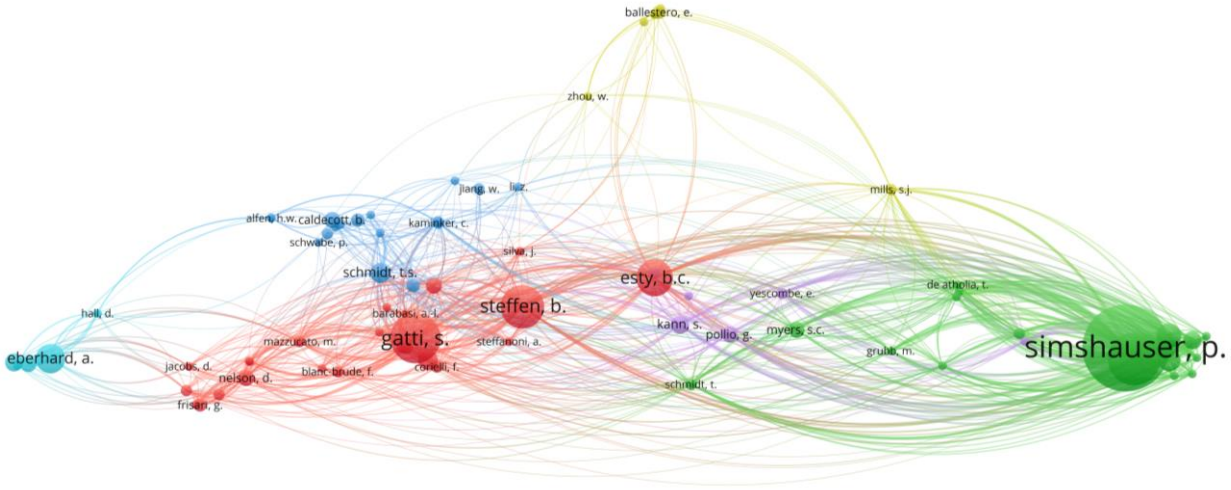



**Figure 9.** Network of co-citation between authors.
(Source: Authors' own research using VOSviewer, as well as Scopus and WoS databases).

Furthermore, the co-citation network highlights Stefano Gatti's significant influence within the PF arena. His seminal book, "Project finance in theory and practice" (Gatti, 2018), provides a comprehensive framework encompassing both the theoretical and practical aspects of PF, serving as a cornerstone for further research endeavors within PF and RE arena. Noteworthy, his book falls outside the scope of **Table 3** due to its comprehensive nature and focus on general PF principles; there is a similar case with authors such as Benjamin C. Esty, and Mariana Mazzucato, they are frequently cited in studies that encompass PF topics.

On the other hand, the research of Simshauser et al. (2022, 2023) stands out for its development of a comprehensive conceptual framework that fosters interdisciplinary connections between PF and RE with several other fields of knowledge, as discussed in earlier sections 3.1.2., and 3.2.1. Their prominent presence within the co-citation network can be attributed to several factors. Notably, Simshauser has emerged as a prolific researcher in recent years, consistently contributing to the field. Additionally, their collaborative work with other scholars within PF and RE undoubtedly strengthens their network position. Furthermore, their research likely incorporates citations to seminal works within the domain, further solidifying their connections within the broader intellectual landscape.

### 3.4.2. Co-authorship analysis

As evidence of collaborative endeavors in producing joint studies, **Figure 10** visually depicts the connections between researchers in the field of PF and RE. The colored lines elegantly link these academic leaders, representing the vital interplay among their contributions and revealing potential author groups passionately focused on studying PF and RE. Each line signifies a connection forged through shared interests and common pursuits in this transformative domain. Moreover, the significance of the identified network is conveyed through the weight attributes assigned to each item's size. These values allow to observe the pivotal role specific researchers play in this intellectual arena, shedding light on the most influential pieces that shape the discourse on PF and RE arena.

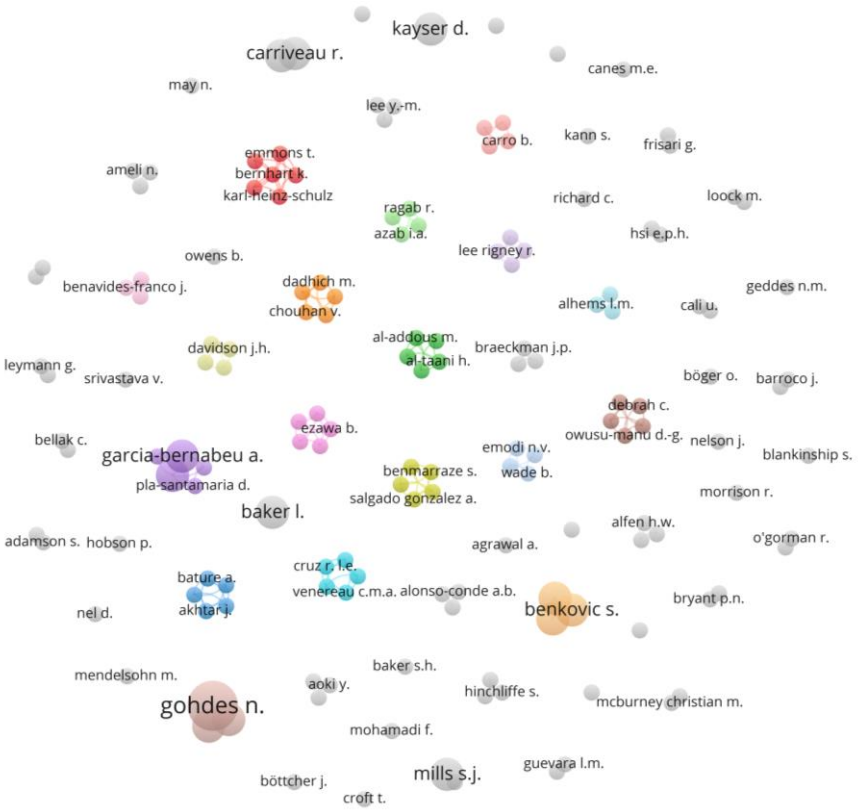



**Figure 10.** Co-authorship network.

Source: Author's own research using VOSviewer, as well as Scopus and WoS databases.

**Figure 10** offers a compelling visual representation of the collaborative networks that characterize research endeavors in PF and RE field. The colored lines illustrate the connections between leading scholars within the field. These linkages highlight the vital interplay between their research contributions and potentially reveal the formation of author groups with a shared passion for PF and RE domains. Each line signifies a collaborative effort forged through shared research interests and a common pursuit of advancing knowledge in this transformative arena.

Furthermore, the network incorporates weight attributes reflected in the size of each node. This approach allows researchers to identify the pivotal roles played by specific scholars within the intellectual landscape of PF and RE landscape. By analyzing the size of the nodes, we can gain valuable insights into the most influential

works that shape the ongoing discourse on PF and RE arena.

The density of connections between co-authors serves as a crucial indicator of their relative prominence within the analyzed bibliographic dataset (Gonzalez-Ruiz et al., 2019). These interweaving lines form a tapestry of intellectual collaboration, where each researcher's contribution adds a vital thread to the collective understanding of PF and RE field. This comprehensive analysis not only underscores the collaborative spirit of these academics but also emphasizes the significance of their individual and collective efforts in shaping the evolving landscape of PF and RE landscape. As studies continue to flourish, this interconnected knowledge network can be expected to serve as a fertile ground for fostering further advancements toward a financially and infrastructurally feasible energy sector.

This section analyzed a total of 156 authors, **Figure 10** presents all of them for a comprehensive view of the current research landscape within PF and RE arena. This decision reflects the relatively nascent stage of development in this field. Notably, a significant portion of the research has been published recently, highlighting the growing interest and scholarly activity. The analysis identified a total of 67 distinct clusters within the co-authorship network. Interestingly, most of these clusters comprise authors with low levels of collaboration.

While the co-authorship network in **Figure 10** reveals the presence of collaborative ties among researchers in the PF and RE domain, it is crucial to acknowledge the distinction between these connections and genuine research collaborations. The observed linkages may represent instances of co-authorship driven by shared interests or specific projects, rather than reflecting the formation of cohesive research groups engaged in sustained collaborative endeavors.

This observation aligns with the identification of numerous clusters within the network, many of which comprise authors with relatively low levels of collaboration. This pattern suggests that the PF and RE research landscape is still characterized by a prevalence of individual or small-group research efforts, with limited evidence of large-scale, inter-institutional collaborations.

Despite the current prevalence of individual and small-group research, the existence of collaborative networks among PF and RE researchers holds promise for future advancements in the field. As these networks continue to evolve, there is potential for the emergence of more formalized research groups bringing together diverse perspectives and expertise to tackle complex PF and RE challenges. Such collaborations could foster groundbreaking research with the potential to transform the PF and RE landscape and contribute to a more financially inclusive and socially conscious world.

## 4. Discussion

Understanding the evolution of the intellectual structure of PF and research through scientometric techniques allowed a better understating of the status quo and trending topics for future study design. Thus, this study offered a comprehensive way of conducting scientometric analysis, which can be used in other areas of knowledge. The following section will present a detailed discussion of the research findings, addressing the five RQs outlined in the introduction section.

RQ1 and RQ2 encompass the current state-of-the-art in the PF and RE arena and the nature of the lending studies in this field. From a quantitative perspective, the results obtained in this stage can be divided into four key findings. First, there has been a recent evident and unexpected scarcity of studies within this field, with low growth and volume of publications. Nonetheless, citations per study showed a persistent trend featuring a decent amount of high-impact research. This phenomenon implies a substantial interest by researchers in this area. The second find comprehends the pivotal role of countries like the United Kingdom, Australia, the USA, and Germany and their academic institutions in developing this field of knowledge. Although there is little concentration in some sources, the research exhibits dissemination across various journals and countries. The third relevant observation is rooted in the phenomenon characterized by a high number of sources related to broad energy and sustainability areas with a comparatively limited contribution from the fields of finance and economics; this represents a potential knowledge gap within these fields that could be addressed in further research. The fourth result reveals that there is a close relationship between theory and practice within this field, attested in approaches through the use of case studies (Barroco and Herrera, 2019; Kayser, 2016; Rafique et al., 2018; Rickman et al., 2022; Spasenic et al., 2022a, 2022b). This opens the gate for both theoretical and practical research outside of the scope of case studies.

RQ3 and RQ4 focused on delving into the thematic landscape of the PF and RE domains. This analysis aimed to identify the key themes that have emerged and gained prominence within the field through the employing of co-occurrence analysis and citation frequency analysis techniques on the retrieved publications. By exploring these evolving thematic trends, the research sought to uncover potential avenues for improvement in both practical applications and theoretical advancements within PF and RE arena. As anticipated, prominent and trending topics have emerged in this nascent research field. These encompass PF and RE itself since there are researchers that have explored this relationship (Böttcher, 2020; Spasenic et al., 2022; Steffen, 2018), various RE resources (solar, wind, hydro), infrastructure development, financial considerations, risk management and perception alongside risk assessment, sustainability principles, and policy frameworks, among others. As discussed previously, while a commendable breadth of coverage exists, with at least one publication addressing nearly all identified topics, this should not be misconstrued as a comprehensive exploration of the entire knowledge frontier. By making a comparison with the existing body of research, several areas remain relatively unexplored, including technological advancements, diverse cost approaches, valuation methodologies, taxation, and other policy considerations. Noteworthily, addressing this prevalent underdevelopment necessitates further research endeavors. A substantial increase in the volume of scholarly studies dedicated to both prominent and newly emerging themes is crucial to advancing the existing knowledge frontier within the field.

Finally, RQ5 delved into collaborative research efforts within the PF and RE arena. This analysis aimed to identify the most prominent researchers and leading intellectual clusters by examining patterns of joint research endeavors. Bibliographic coupling techniques were employed to achieve this objective. The result deviates from the common expectation within academia, where collaborative research efforts are

encouraged and fostered. The prevalence of individual or small-group research efforts, with limited evidence of large-scale, inter-institutional collaborations, presents a somewhat unexpected result within the context of the PF and RE research landscape. Regardless of the currently observed prevalence of individual and small-group research, collaborative networks among PF and RE researchers hold promise for future advancements in the field. As these networks continue to evolve, there is potential for the emergence of more formalized research groups bringing together diverse perspectives and expertise to tackle complex PF and RE challenges. Such collaborations could foster groundbreaking research with the potential to transform the PF and RE landscape and contribute to a more financially inclusive and socially conscious world.

Despite the progress in this research domain, it is crucial to acknowledge that the PF and RE project financing field remains far from fully explored. A significant number of topics within this domain necessitate further investigative efforts. This highlights the importance of ongoing research endeavors to solidify the knowledge base and address these nascent areas. Further research should consider using a broader spectrum of scientometric tools and include even more data from gray literature.

As the global community navigates the critical journey towards a successful energetic transition, the need for robust academic and practical support within the field of PF and RE will undoubtedly intensify over time. Collaborative efforts between scholars and practitioners will be instrumental in propelling advancements in knowledge, developing the pivotal role of PF as an important financing solution, and ultimately facilitating the successful construction and execution of policies strengthen RE projects as a core aspect of a sustainable world.

## 5. Conclusions

This study leveraged a comprehensive scientometric analysis to unveil cutting-edge research within PF and RE arena. In this way, this article has not only provided a comprehensive overview of the research landscape but has also facilitated a deeper understanding of the progress achieved in integrating new insights within PF and RE infrastructure research. This multifaceted analysis has yielded valuable insights into prominent scholars, influential publications, and seminal studies that have significantly shaped the current direction of the PF and RE field. Furthermore, the analysis examines the interconnectedness between studies and authors, thereby revealing their pivotal role in shaping the discourse within this domain.

Our findings align with potential topics for future exploration, including the role of technological advancements within the field, diverse cost approaches, valuation methodologies, and taxation and other policy considerations. Also, the already addressed but scarce topics by recent research require future expanded explorations. By affording insights into the present and future landscape of PF and RE infrastructure research, this study contributes to a comprehensive evolution and offers pointers toward potential paths. In the same way, talking about future paths, this study highlights the need for continued investigation by finance and economics-related journals and researchers. By fostering collaboration between these disciplines, we can bridge the knowledge gap regarding the intersection of PF and RE arena, which has

been extensively but almost solely explored by journals related to energy and other areas, as demonstrated in previous sections.

This study shed light on the current state of PF and RE infrastructure and indicated ways for researchers and practitioners to unexplored topics. As fields of knowledge such as energy and finance continue to engage and enlarge through topics as sustainability, the issue of addressing the relationship between PF and RE infrastructure gains prominence, and our work stands as a guiding beacon in this dynamic evolution. Beyond the initial exploration of collaboration patterns, further research endeavors within the PF and RE domains hold immense potential for advancing knowledge and informing best practices. Delving deeper into the details of PF models tailored explicitly for RE infrastructure projects is an essential avenue for future investigation. This includes a comprehensive examination of the factors that influence the cost of capital for RE projects financed through PF, the effectiveness of various risk mitigation strategies, and the optimal financing structures for diverse project types. Additionally, a thorough analysis of the interplay between PF and RE with broader market dynamics, such as the influence of government policies and incentive structures on project feasibility and investor behavior, is crucial for fostering a more robust and sustainable RE sector. Also, further exploration of the risks associated with PF and RE projects and examination of how capital structure influences the profitability of these projects could shed light on optimal financing strategies. These multifaceted research endeavors can equip stakeholders with the necessary knowledge to optimize PF strategies, attract investments, and ultimately accelerate the transition toward a clean energy future.

**Author contributions:** Conceptualization, JDGR; methodology, JDGR and NJMR; software, SGV; validation, JDGR and NJMR; formal analysis, SGV and JDGR; investigation, SGV and JDGR; data curation, SGV; writing—original draft preparation, SGV, JDGR, and NJMR; writing—review and editing, SGV, JDGR, and NJMR; visualization, SGV. All authors have read and agreed to the published version of the manuscript.

**Acknowledgments:** We extend our sincere gratitude to the reviewers and editor for their insightful comments, which have significantly enhanced the quality of this study.

**Conflict of interest:** The authors declare no conflict of interest.

## References

Agrawal, A. (2012). Risk mitigation strategies for renewable energy project financing. Strategic Planning for Energy and the Environment, 32(2), 9–20. https://doi.org/10.1080/10485236.2012.10554231

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of Informetrics, 11(4), 959–975. https://doi.org/10.1016/J.JOI.2017.08.007

Baker, L. (2015). The evolving role of finance in South Africa's renewable energy sector. Geoforum, 64, 146–156. https://doi.org/10.1016/j.geoforum.2015.06.017

Baker, L. (2022). Procurement, finance and the energy transition: Between global processes and territorial realities. Environment and Planning E: Nature and Space, 5(4), 1738–1764. https://doi.org/10.1177/2514848621991121

Baker, S. H. (2015). Project finance and sustainable development in the global south. In: International Environmental Law and the Global South. Cambridge University Press. pp. 338–355. https://doi.org/10.1017/CBO9781107295414.017

Barroco, J., & Herrera, M. (2019). Clearing barriers to project finance for renewable energy in developing countries: A

Philippines case study. Energy Policy, 135. https://doi.org/10.1016/j.enpol.2019.111008

Bature, A., Melville, L., Mizanur Rahman, K., et al. (2018). An investigation into the effects of risks and risk management of bioenergy projects. E3S Web of Conferences, 61, 0006. https://doi.org/10.1051/e3sconf/20186100006

Benavides-Franco, J., Gómez, J. M., & Pérez-Uribe, M. A. (2023). Determinants of Project Finance success for renewable energy. Renewable Energy, 211, 188–201. https://doi.org/10.1016/j.renene.2023.04.031

Bloomberg, N. E. F. (2024). Energy Transition Investment Trends 2024. Available online: https://about.bnef.com/energy-transition-investment/ (accessed on 25 March 2024).

Böttcher, J. (2020). Project finance of a renewable energy project. In: Green Banking: Realizing Renewable Energy Projects. De Gruyter. pp. 177–222. https://doi.org/10.1515/9783110607888-006

Braeckman, J. P., Markkanen, S., & Seega, N. (2022). Financiers' perceptions of risk in relation to large hydropower projects. Environmental Research: Infrastructure and Sustainability, 2(1). https://doi.org/10.1088/2634-4505/ac4e70

Culnan, M. J. (1987). Mapping the Intellectual Structure of MIS, 1980–1985: A Co-Citation Analysis. MIS Quarterly, 11(3), 341. https://doi.org/10.2307/248680

Duffy, A., Hand, M., Wiser, R., et al. (2020). Land-based wind energy cost trends in Germany, Denmark, Ireland, Norway, Sweden and the United States. Applied Energy, 277, 114777. https://doi.org/10.1016/j.apenergy.2020.114777

Dwivedi, R., Nerur, S., & Balijepally, V. (2023). Exploring artificial intelligence and big data scholarship in information systems: A citation, bibliographic coupling, and co-word analysis. International Journal of Information Management Data Insights, 3(2), 100185. https://doi.org/10.1016/j.jjimei.2023.100185

Emodi, N. V, Wade, B., Rekker, S., & Greig, C. (2022). A systematic review of barriers to greenfield investment in decarbonisation solutions. Renewable and Sustainable Energy Reviews, 165. https://doi.org/10.1016/j.rser.2022.112586

Firouzi, A., & Meshkani, A. (2021). Risk-based optimization of the debt service schedule in renewable energy project finance. Utilities Policy, 70. https://doi.org/10.1016/j.jup.2021.101197

Frisari, G., & Stadelmann, M. (2015). De-risking concentrated solar power in emerging markets: The role of policies and international finance institutions. Energy Policy, 82(1), 12–22. https://doi.org/10.1016/j.enpol.2015.02.011

Garcia-Bernabeu, A., Mayor-Vitoria, F., Bravo, M., & Pla-Santamaria, D. (2019). Financial risk management in renewable energy projects: A multicriteria approach. Journal of Management Information and Decision Sciences, 22(4), 360–371.

Gatti, S. (2018). Introduction to the Theory and Practice of Project Finance. In: Project Finance in Theory and Practice. Elsevier. pp. 1–42. https://doi.org/10.1016/B978-0-12-811401-8.00001-5

Global Infrastructure Hub. (2018). Global Infrastructure Outlook: Investment forecasts for Energy. Available online: https://outlook.gihub.org/sectors/energy (accessed on 25 March 2024).

Gohdes, N., Simshauser, P., & Wilson, C. (2022). Renewable entry costs, project finance and the role of revenue quality in Australia's National Electricity Market. Energy Economics, 114. https://doi.org/10.1016/j.eneco.2022.106312

Gohdes, N., Simshauser, P., & Wilson, C. (2023). Renewable investments, hybridised markets and the energy crisis: Optimising the CfD-merchant revenue mix. Energy Economics, 125. https://doi.org/10.1016/j.eneco.2023.106824

Gonzalez-Ruiz, J. D., Arboleda, A., Botero, S., & Rojo, J. (2019). Investment valuation model for sustainable infrastructure systems. Engineering, Construction and Architectural Management, 26(5), 850–884. https://doi.org/10.1108/ECAM-03-2018-0095

Gonzalez-Ruiz, J. D., Marín-Rodríguez, N. J., & Weber, O. (2024). New insights on social finance research in the sustainable development context. Business Strategy & Development, 7(1). https://doi.org/10.1002/bsd2.342

González-Ruiz, J. D., Mejía-Escobar, J. C., Rojo-Suárez, J., & Alonso-Conde, A. B. (2023). Green Bonds for Renewable Energy in Latin America and the Caribbean. The Energy Journal, 44(5), 45–66. https://doi.org/10.5547/01956574.44.4.jgon

Haghani, M. (2023). What makes an informative and publication-worthy scientometric analysis of literature: A guide for authors, reviewers and editors. Transportation Research Interdisciplinary Perspectives, 22, 100956. https://doi.org/10.1016/J.TRIP.2023.100956

Hirsch, J. E. (2005). An index to quantify an individual's scientific research output. Proceedings of the National Academy of Sciences, 102(46), 16569–16572. https://doi.org/10.1073/pnas.0507655102

IEA. (2024). Electricity 2024—Analysis and forecast to 2026. Available online: https://www.iea.org/reports/electricity-2024 (accessed on 25 March 2024).

In, S. Y., Manav, B., Venereau, C. M. A., et al. (2022). Climate-related financial risk assessment on energy infrastructure investments. Renewable and Sustainable Energy Reviews, 167. https://doi.org/10.1016/j.rser.2022.112689

Kahn, E. (1996). The production tax credit for wind turbine powerplants is an ineffective incentive. Energy Policy, 24(5), 427–435. https://doi.org/10.1016/0301-4215(96)00014-6

Kann, S. (2009). Overcoming barriers to wind project finance in Australia. Energy Policy, 37(8), 3139–3148. https://doi.org/10.1016/j.enpol.2009.04.006

Kayser, D. (2013). Recent research in project finance a commented bibliography. Procedia Computer Science, 17, 729–736. https://doi.org/10.1016/j.procs.2013.05.094

Kayser, D. (2016). Solar photovoltaic projects in China: High investment risks and the need for institutional response. Applied Energy, 174, 144–152. https://doi.org/10.1016/j.apenergy.2016.04.089

Korom, P. (2019). A bibliometric visualization of the economics and sociology of wealth inequality: A world apart? Scientometrics, 118(3), 849–868. https://doi.org/10.1007/s11192-018-03000-z

Kumari, A., & Singh, M. P. (2023). A journey of social sustainability in organization during MDG & SDG period: A bibliometric analysis. Socio-Economic Planning Sciences, 88, 101668. https://doi.org/10.1016/j.seps.2023.101668

Li, H., Wu, M., Wang, Y., & Zeng, A. (2022). Bibliographic coupling networks reveal the advantage of diversification in scientific projects. Journal of Informetrics, 16(3), 101321. https://doi.org/10.1016/j.joi.2022.101321

Lundan, S., & Leymann, G. (2021). Investing in sustainable infrastructure: new directions for international business research. Transnational Corporations, 28(3), 147–157. https://doi.org/10.18356/2076099x-28-3-7

May, N. (2017). The impact of wind power support schemes on technology choices. Energy Economics, 65, 343–354. https://doi.org/10.1016/j.eneco.2017.05.017

Middleton Jr., G. L., & McBurney, C. M. (1993). New energy policy act's "green tax" package will benefit project finance. Strategic Planning for Energy and the Environment, 12(4), 23–27.

Miller, L., & Carriveau, R. (2018). A review of energy storage financing—Learning from and partnering with the renewable energy industry. Journal of Energy Storage, 19, 311–319. https://doi.org/10.1016/j.est.2018.08.007

Mills, S. J. (1993). Project finance for alternative energy. IEE Conference Publication, 385, 207–211.

Mohamadi, F. (2021). Introduction to project finance in renewable energy infrastructure: Including public-private investments and non-mature markets. In: Introduction to Project Finance in Renewable Energy Infrastructure: Including Public-Private Investments and Non-Mature Markets. Springer Cham. https://doi.org/10.1007/978-3-030-68740-3

Mora, E. B., Spelling, J., van der Weijde, A. H., & Pavageau, E. M. (2019). The effects of mean wind speed uncertainty on project finance debt sizing for offshore wind farms. Applied Energy, 252, 113419. https://doi.org/10.1016/j.apenergy.2019.113419

Nelson, J. (2020). Australia's National Electricity Market: Financing the transition. Electricity Journal, 33(9). https://doi.org/10.1016/j.tej.2020.106834

Nickerson, T. A., Hathaway, B. J., Smith, T. M., & Davidson, J. H. (2015). Economic assessment of solar and conventional biomass gasification technologies: Financial and policy implications under feedstock and product gas price uncertainty. Biomass and Bioenergy, 74, 47–57. https://doi.org/10.1016/j.biombioe.2015.01.002

Ozturk, O. (2021). Bibliometric review of resource dependence theory literature: an overview. Management Review Quarterly, 71(3), 525–552. https://doi.org/10.1007/S11301-020-00192-8/TABLES/8

Öztürk, O., Kocaman, R., & Kanbach, D. K. (2024). How to design bibliometric research: An overview and a framework proposal. Review of Managerial Science. https://doi.org/10.1007/s11846-024-00738-0

Pranckutė, R. (2021). Web of Science (WoS) and Scopus: The Titans of Bibliographic Information in Today's Academic World. Publications, 9(1), 12. https://doi.org/10.3390/publications9010012

Rafique, M. M., Rehman, S., & Alhems, L. M. (2018). Developing zero energy and sustainable villages—A case study for communities of the future. Renewable Energy, 127, 565–574. https://doi.org/10.1016/j.renene.2018.04.087

Rickman, J., Larosa, F., & Ameli, N. (2022). The internal dynamics of fast-growing wind finance markets. Journal of Cleaner Production, 375. https://doi.org/10.1016/j.jclepro.2022.134129

Shiau, W. L., Wang, X., & Zheng, F. (2023). What are the trend and core knowledge of information security? A citation and co-citation analysis. Information & Management, 60(3), 103774. https://doi.org/10.1016/j.im.2023.103774

Spasenic, Z., Makajic-Nikolic, D., & Benkovic, S. (2022a). Integrated FTA-risk matrix model for risk analysis of a mini hydropower plant's project finance. Energy for Sustainable Development, 70, 511–523. https://doi.org/10.1016/j.esd.2022.08.024

Spasenic, Z., Makajic-Nikolic, D., & Benkovic, S. (2022b). Risk assessment of financing renewable energy projects: A case study of financing a small hydropower plant project in Serbia. Energy Reports, 8, 8437–8450.

https://doi.org/10.1016/j.egyr.2022.06.065

Spasenic, Z., Milosavjevic, M., & Milanovic, N. (2022). Project financing of renewable energy projects a bibliometric analysis and future research agenda. Fresenius Environmental Bulletin, 31, 7844–7851.

Srivastava, V. (2023). Project Finance for Green Renewable Energy Assets: Does It Solve the Higher Cost of Capital Conundrum? Journal of Structured Finance, 28(4), 59–69. https://doi.org/10.3905/jsf.2022.1.148

Steffen, B. (2018). The importance of project finance for renewable energy projects. Energy Economics, 69, 280–294. https://doi.org/10.1016/j.eneco.2017.11.006

Tseng, Y. C., Lee, Y. M., & Liao, S. J. (2017). An integrated assessment framework of offshore wind power projects applying equator principles and social life cycle assessment. Sustainability (Switzerland), 9(10). https://doi.org/10.3390/su9101822

Vázquez-Vázquez, M., Alonso-Conde, A. B., & Rojo-Suárez, J. (2021). Are the purchase prices of solar energy projects under development consistent with cost of capital forecasts? Infrastructures, 6(7). https://doi.org/10.3390/infrastructures6070095

van Eck, N. J., & Waltman, L. (2020). VOSviewer manual. In: Leiden: Univeristeit Leiden. Universiteit Leiden.

Weber, B., Staub-Bisang, M., & Alfen, H. W. (2016). Infrastructure as an asset class: Investment strategy, sustainability, project finance and PPP. In: Infrastructure as an Asset Class: Investment Strategy, Sustainability, Project Finance and PPP. John Wiley & Sons, Ltd. https://doi.org/10.1002/9781119226574

Zhang, M., Wang, X., Chen, X., et al. (2022). A Scientometric Analysis and Visualization Discovery of Enhanced Recovery After Surgery. Frontiers in Surgery, 9. https://doi.org/10.3389/fsurg.2022.894083

Zhu, J., & Liu, W. (2020). A tale of two databases: the use of Web of Science and Scopus in academic papers. Scientometrics, 123(1), 321–335. https://doi.org/10.1007/s11192-020-03387-8