“Renewable energy sources and the shadow economy: Social responsibility against tax evasion”

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RENEWABLE ENERGY SOURCES AND THE SHADOW ECONOMY: SOCIAL RESPONSIBILITY AGAINST TAX EVASION

Abstract

The interconnection between renewable energy development and the shadow economy has become increasingly important as governments pursue sustainability objectives alongside fiscal transparency and the fight against tax evasion. This study aims to analyze how informal economic activity shapes the deployment of renewable energy and how renewable initiatives may support economic formalization and social responsibility. A bibliometric study of 161 documents retrieved from Scopus and Web of Science was conducted using Biblioshiny, assessing metadata completeness, thematic structures, author productivity, and collaboration networks. The results show excellent metadata coverage (abstracts, titles, and document types at 100%), though cited references were completely missing (100%), with keywords absent in 18% of records. Research output accelerated after 2015, with 2020 being the year with the highest citation velocity (7.81 citations/year), driven by two publications with over 100 citations each. Thematic mapping identified "renewable energy," "shadow economy," and "sustainable development goals" as motor themes, while "circular economy" and "policy uncertainty" emerged as basic but growing clusters. International collaboration accounted for 38% of documents, though single-country studies remain dominant, and citation analysis revealed a steady rise in impact, with top sources surpassing 120 citations. The analysis confirms a growing yet fragmented field, highlights the dual role of informality, from undermining fiscal revenues to supporting decentralized energy, and points to governance, circular economy, and policy risk as critical areas for future research.

Keywords renewable energy, shadow economy, informal sector, tax evasion, social responsibility, bibliometric analysis

JEL Classification H26, O27, Q56, Q42, C89

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INTRODUCTION

The intersection between renewable energy development and the shadow economy, particularly in the context of tax evasion and social responsibility, has become increasingly relevant in the face of global sustainability and governance challenges (Vătavu et al., 2025). As countries strive to meet their climate commitments and transition to cleaner energy systems, the integrity and transparency of economic structures play a critical role in ensuring the effectiveness of such efforts. The OECD (2020) and Blazey and Lelong (2022) highlight that illicit financial flows, tax evasion, and informal economic activity significantly constrain governments' ability to finance green transitions. The report emphasizes that transparent and accountable tax systems are crucial for mobilizing domestic revenues to support investments in recent renewable energy infrastructure, clean technology subsidies, and climate resilience. Countries with large informal economies often struggle to meet climate targets due to limited fiscal space and institutional weaknesses. The IEA (2020) directly links the success of clean energy transitions to strong governance, institutional integrity, and reduced corruption (Wen et al., 2023). It warns that renewable energy

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investments face higher financial risks, regulatory uncertainty, and lower accountability in countries where informal or shadow markets dominate. These conditions deter foreign and domestic investment in renewables and allow unregulated energy use (e.g., illegal biomass burning or off-grid diesel) to persist, undermining national decarbonization strategies and contributing to environmental harm.

The shadow economy, comprising informal, unreported, or illicit economic activities (Schneider, 2004), presents a significant obstacle to financing and implementing renewable energy projects. Tax evasion within this sector undermines public revenues that could otherwise be allocated toward green infrastructure, subsidies, and innovation in clean technologies. Moreover, the lack of regulatory oversight in informal sectors generally leads to unsustainable practices, inefficiencies, and environmental degradation. Thus, the Boston Consulting Group highlights that an expanding shadow economy leads to significant societal issues, including lost tax revenues. These lost revenues diminish the government's capacity to fund essential public services and investments, such as renewable energy infrastructure and clean technology innovation (Sanchez et al., 2023). The IIED (2016) notes that the informal economy operates outside government regulation and sustains a large portion of the global workforce. However, the lack of regulation in this particular sector leads to environmental challenges, such as unsafe working conditions and unsustainable practices, thus further contributing to environmental degradation and undermining efforts toward sustainable development, including implementing renewable energy projects.

At the same time, the growth of renewable energy sectors brings new opportunities for promoting formal employment, tax compliance, and corporate social responsibility. By fostering transparent business practices and encouraging energy producers and consumers to operate within the legal framework, renewable energy initiatives can serve as a tool to counteract the dynamics of the shadow economy. This creates a dual benefit: advancing environmental goals while strengthening economic governance and public trust. Renewable energy corporations such as EDF Renewables (2024) highlight that their renewable energy projects contribute positively to host communities by generating employment opportunities and increasing tax revenues. Even though the scientific assessment of respective employment effects turns out more cautious, it is predominantly positive, too (Stavropoulos & Burger, 2020; Hanna et al., 2024).

Given the global push for a just and inclusive energy transition, especially in developing and emerging economies where the shadow economy constitutes a large share of GDP, this topic holds high practical and policy relevance. Understanding the interplay between renewable energy and informal economic activity is essential for designing strategies that reduce tax evasion and ensure equitable and sustainable development.

1. LITERATURE REVIEW

Understanding the relationship between renewable energy development and the shadow economy requires a multidimensional analytical approach. A growing body of research highlights tax evasion, ethical responsibility, and governance frameworks as key intersection points. The scholarly landscape in this area increasingly relies on bibliometric methods to map developments, identify research gaps, and support evidence-based policy direction.

Bibliometric tools have effectively systematized knowledge across sustainability and economic governance research. As topic prominence analysis and trend detection gain traction, they offer refined ways to understand the evolution of scholarly attention and its alignment with societal challenges (Donthu et al., 2021; Klavans & Boyack, 2017). Recent studies show how these tools have been employed to chart developments in management, ethics, trade, and sustainability, demonstrating the broad applicability of bibliometric mapping to governance issues and green transition policies (Abbasova, 2023; Li & Hassan, 2023; Prieto-Gutierrez et al., 2023; Tran Viet & Phan Thanh, 2024).

In the field of renewable energy, scholarly attention increasingly focuses on investment conditions, fiscal environments, and the role of policy instru-

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ments in enabling or constraining clean energy deployment. Evidence confirms that stable financial instruments, such as feed-in tariffs, risk guarantees, and tax incentives, are critical in reducing investor uncertainty and driving capital flows into the sector (Liu et al., 2023; Moroz & Lyeonov, 2024; Krause et al., 2024; Myroshnychenko et al., 2024; Ziabina et al., 2023). Beyond financial instruments, governance quality and institutional integrity significantly shape renewable energy investment environments. Studies underscore that countries with lower regulatory risk and stronger rule of law attract more consistent flows of renewable energy investment, particularly in the case of start-ups and minority investors operating in new markets (Dobrovolska et al., 2024a; Halynskyi & Telizhenko, 2024; Sotnyk et al., 2023). Broader financial system resilience is likewise positioned as a prerequisite for energy transition, as systemic instability amplifies capital flight and undermines long-term infrastructure projects (Polzin et al., 2017). An illustrative example is provided by Vietnam, where introducing a fixed feed-in tariff in 2017 led to a rapid and unprecedented expansion of solar PV capacity, demonstrating the transformative potential of targeted and stable policy support (Apfel & Herbes, 2021). However, subsequent policy reversals and payment delays created uncertainty, underscoring that long-term credibility and regulatory continuity are as important as the incentive (Chu et al., 2023). This aligns with international evidence that policy inconsistency and informal practices, often present in countries with large shadow economies, discourage formal investment in clean technologies (IEA, 2020; OECD, 2020; Mateo-Sagasta et al., 2015; Makarenko et al., 2023). Thus, a transparent and predictable regulatory environment, supported by enforceable contracts and investor protections, is essential to bridge the gap between climate ambition and capital mobilization.

The shadow economy remains a structural impediment to such transitions, as it distorts fiscal policy effects and discourages formal investment. Governance reforms and transparency-enhancing measures are identified as essential tools for aligning fiscal competition with shadow economy suppression (Mazurenko et al., 2023). Historical analogies, such as the impact of the 2008 financial crisis on the expansion of the informal sector, underscore the potential risks of policy failures in times of economic uncertainty (Balas & Kaya, 2024). Further studies link judicial inefficiency and high tax burdens to growing informality and capital flight, reinforcing the need for institutional reform and tax policy recalibration (Dobrovolska et al., 2024b).

Beyond regulatory and fiscal considerations, innovation ecosystems and university-industry partnerships are seen as mechanisms to reduce informality by embedding ethical management practices and cross-sector collaboration. This perspective aligns with broader research into sustainability reporting, behavioral ethics, and trust as a cornerstone of open innovation, particularly in the SME segment (Samoilikova et al., 2023; Correa Porcel et al., 2024; Streimikiene et al., 2023; Runiewicz-Wardyn & Winogradska, 2023).

A growing research stream explores the intersection of clean energy development, environmental awareness, and public health. Empirical evidence confirms that transitioning to renewable energy reduces pollutant emissions and improves health outcomes, particularly in urban and industrialized regions (Badreddine & Larbi Cherif, 2024; Matvieieva et al., 2023). This is further supported by Google Trends analyses, which highlight increasing public concern over climate and energy-related issues (Dasandi et al., 2025; Erokhin & Komendantova, 2024; Hrytsenko et al., 2024). Public engagement strategies, including targeted media communication, have proven effective in encouraging energy-conscious behavior (Piwowarski, 2024).

Another line of research highlights the role of small and medium-sized enterprises in advancing sustainable development. Evidence from EU contexts shows that SME growth aligns with progress on Sustainable Development Goals, suggesting that local business dynamics can strengthen national energy and fiscal reform agendas (Kovalov, 2024). These relationships become more complex in times of crisis. For example, the Russia-Ukraine war has significantly shifted research and policy attention toward resilience, decentralization, and informality in energy transitions (Ostapenko et al., 2023). Wartime disruption has also intensified the focus on Ukraine's bioenergy potential and institutional capacity to sustain clean energy strategies (Kurbatova et al., 2023; Kuzior et al., 2021).

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Digitalization brings both opportunities and threats. On the one hand, cybercrime and digital vulnerabilities pose a growing risk to financial transparency and investor confidence in the renewable energy sector (Kuzior et al., 2022, 2024). On the other hand, education systems that integrate digital skills and national security objectives can contribute to economic formalization and behavioral change (Samusevych et al., 2021; Onopriienko et al., 2023; Koblianska et al., 2023). These perspectives are enriched by emerging methods, such as Google Trends and AI-based modelling, that help forecast citizen behavior and smart city evolution (Hrytsenko et al., 2024).

Across the literature, curbing tax evasion and shadow-economy activity during energy transitions requires complementary levers beyond formal rule-making, namely ethical leadership, sustained public engagement, institutional resilience, and transparent fiscal governance. Bibliometric mapping of this field clarifies a mature core around renewable energy, informality, and sustainability, while highlighting adjacent but underdeveloped areas, such as policy uncertainty, circular economy, and waste systems. That connects governance and market behavior. Read together, these strands imply testable expectations that guide subsequent inquiry. First, rising environmental salience in the public sphere is likely to co-move with shifts toward formal energy use and tax compliance. Second, the expansion of small and medium-sized enterprises can align local practices with national energy and fiscal frameworks, particularly under decentralized governance. Third, robust responses to cyber risk, coupled with digital-skills development, appear to strengthen investor confidence and accelerate economic formalization within clean-energy markets. This synthesis positions bibliometric evidence as a way to track how knowledge evolves and as a strategic compass for shaping policy-relevant, hypothesis-driven research.

This study aims to conduct a bibliometric analysis of the scholarly literature at the intersection of the shadow economy and renewable energy development, to map thematic trends, evaluate research productivity, and identify conceptual linkages and knowledge gaps, particularly concerning tax evasion, governance, and social responsibility in the context of clean energy transitions.

2. METHODOLOGY

This study employs a systematic literature review approach to examine the relationship between the shadow economy and renewable energy development. The review focuses on understanding the scope, trends, and knowledge gaps at the intersection of informal economic activities and sustainable energy transitions.

Following an established approach of bibliometric analysis in economics (seminal, Mongeon & Paul-Hus, 2016; comparable, e.g.; Aydaner & Okuyan, 2024), two reputable academic databases, Scopus and Web of Science (WoS), were selected for data collection due to their comprehensive indexing of peer-reviewed literature across multiple disciplines, including economics, energy policy, environmental studies, and social sciences. These platforms were expected to ensure high quality and relevance in retrieved articles.

A targeted search string was developed to capture literature discussing the shadow economy and various forms of renewable energy. The query was designed to account for the diversity of terminology used across the literature. It included synonyms and related concepts for both thematic areas, ensuring broad coverage. The Boolean expression was used in both Scopus and WoS; the search query is presented in Appendix A. This query was applied to the title, abstract, and keywords fields to ensure retrieval of the most relevant literature.

To refine the results, the following inclusion criteria were applied: types of documents (articles, conference papers, books, and book chapters). There are no restrictions on languages, countries, or open access.

The initial query yielded a total of 222 documents (119 documents from the Scopus database and 103 papers from the Web of Science database) combined. After removing duplicates and screening titles and abstracts for relevance, a final sample of 161 articles was selected for full-text review and thematic analysis (on merging Scopus and WoS results) (Caputo & Kargina, 2022).

The overview of metadata quality for the final sample of 161 documents retrieved from Scopus and Web of Science is summarized in Table 1. It reflects the completeness of bibliographic information used for bibliometric analysis.

Table 1. Completeness of metadata in the analyzed document sample

Source: Authors' analysis based on Biblioshiny App.

Metadata	Missing Counts	Missing %	Status
Abstract	0	0.00	Excellent
Document Type	0	0.00	Excellent
Language	0	0.00	Excellent
Publication Year	0	0.00	Excellent
Title	0	0.00	Excellent
Total Citation	0	0.00	Excellent
Author	1	0.62	Good
Journal	1	0.62	Good
Affiliation	5	3.11	Good
DOI	19	11.80	Acceptable
Corresponding Author	28	17.39	Acceptable
Keywords	29	18.01	Acceptable
Keywords Plus	47	29.19	Poor
Science Categories	58	36.02	Poor

3. RESULTS

3.1. General publication trends

The bibliometric summary from Biblioshiny presents a comprehensive view of the academic research focused on the interconnections between the shadow (informal) economy and renewable energy development. The dataset spans from 1984 to 2025, covering over four decades of research. With 161 documents published across 134 sources, it reflects a moderately sized body of literature distributed across various journals, books, and conference proceedings. The annual growth rate of 3.44% suggests that academic interest in this area has been increasing steadily, albeit not rapidly, indicating that it remains a relatively specialized or emerging topic. The average age of the documents is 7.06 years, which points to a balanced presence of both foundational and more recent contributions. On average, each document has received about 17.9 citations, showing that the work in this area is being read and referenced with some frequency, underscoring its academic relevance.

Regarding the content, the corpus features a wide range of terminology, with 860 keywords plus and 606 author-defined keywords, highlighting conceptual diversity and broad thematic engagement. Authorship analysis shows that 478 different authors have contributed to this literature. Only 32 documents are single-authored, accounting for approximately 20% of the total sample, whereas the remaining works involve collaborative efforts, with an average of 3.17 co-authors per document. This indicates a healthy collaboration across borders, as evidenced by the 25.47% rate of international co-authorship. These figures suggest that the topic is academically relevant and of global interest, even though collaboration could be further enhanced.

The types of documents analyzed reveal a dominance of peer-reviewed journal articles (119), supported by contributions in the form of book chapters, whole books, conference papers, editorials, and reviews. This spread suggests both empirical and theoretical engagements and practical explorations presented at conferences. The review papers indicate that efforts have already been made to synthesize knowledge in this domain, which is crucial for shaping future research directions.

Altogether, the results point to a field that is developing steadily with increasing academic attention. The research is marked by conceptual diversity, moderate international collaboration, and solid academic impact. This indicates that the intersection of renewable energy and the informal economy is recognized as a meaningful and multifaceted area of inquiry, attracting scholars from diverse disciplines, particularly those concerned with energy policy, development studies, economics, and sustainability.

Figure 1 illustrates the annual scientific production for documents related to the interconnections between the shadow economy and renewable energy development, as analyzed through Biblioshiny.

The timeline can be divided into two phases:

- The period 1984–1999 (represented by the blue line) shows minimal scientific output, with most years producing zero or one document on this topic. This suggests that the shadow economy and renewable energy connection were not widely researched, which is at least

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Source: Authors' analysis based on Biblioshiny App.

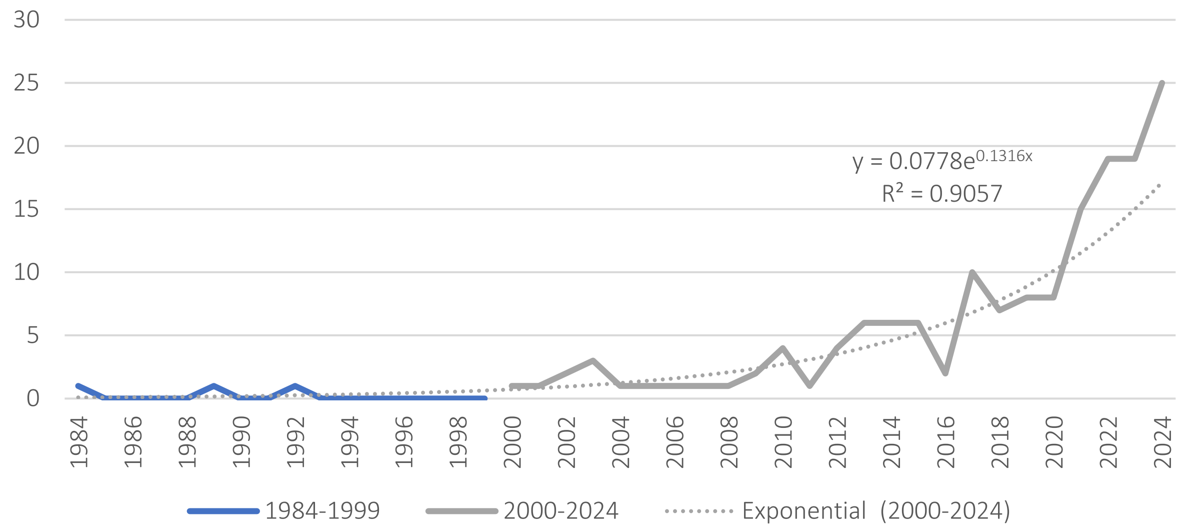

Figure 1. Annual scientific production over time

partly because renewable energy gained its present momentum much later.

- Starting from the early 2000s, there was a gradual (represented by the green line) increase in publications, with notable growth accelerating, especially after 2010. In recent years, the number of documents has increased sharply, reaching a peak of over 25 publications in 2024.

The dotted green line represents an exponential trendline fitted to the 2000–2024 data. The equation $y = 0.0778e^{0.1316x}$ and the high R^2 value of 0.9057 indicate a strong exponential growth trend in scientific production. This means that research interest in this interdisciplinary field is rapidly growing.

3.2. Author and source impact

Figure 2 displays the annual citation performance for documents concerning the interconnection between the shadow (informal) economy and renewable energy development, as analyzed using Biblioshiny.

The field began in 1984 and continued into the early 2000s, with only one publication in most years and low or no citations. However, a few exceptions stand out, such as the single publication of Duffy (2000) with 68 total citations, yielding a relatively high citation rate of 2.62 per year, and van Ruijven et al. (2008), which stands out with 91 citations and a 5.06 citation/year average – the highest up to that time. These early outliers represent seminal contributions to the field of research.

The analysis of average citations per year by publication year reveals that certain years – particularly 2008, 2011, 2015, 2017, and 2020 – also exhibited outstanding citation performance, suggesting the presence of influential, field-shaping publications. This observation is strongly supported by the list of most cited individual articles (see Table 2), which are key contributors to those peaks.

In 2015, which stands out with the highest annual citation rate (6.42 citations per year), Mateo-Sagasta et al. (2015) published a seminal work that has accumulated 314 total citations and 28.55 citations per year – the highest in the dataset. Also, Walwyn and Brent (2015) contributed with a paper receiving 83 citations and averaging 7.55 per year, further boosting the cohort's impact.

The year 2020 stands out with the highest citation velocity in the dataset, averaging 7.81 citations per year, driven primarily by two highly influential publications: Sharma and Jain (2020) (127 citations; 21.17/year) and Kumar and Agrawal (2020) (118 citations; 19.67/year). These works gained rapid scholarly traction not merely due to their timing but because they addressed urgent intersections between

Source: Authors' analysis based on Biblioshiny App.

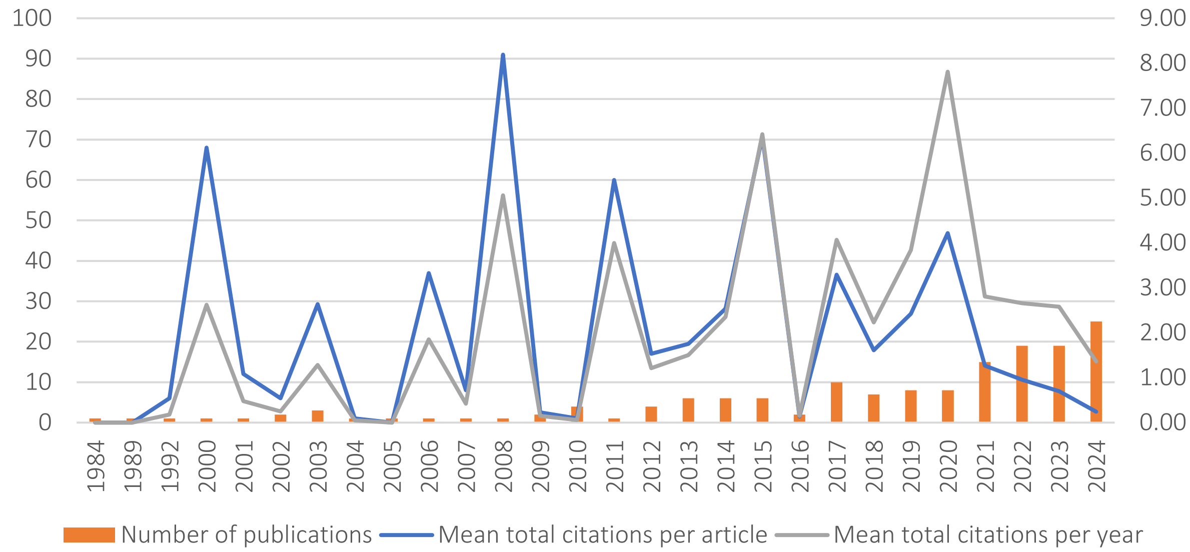

Figure 2. Average citation performance per year

economic informality, environmental policy, and sustainable development, topics increasingly prioritized by policymakers and researchers in the wake of the COVID-19 pandemic and its fiscal aftermath. Sharma and Jain (2020) focused on the political economy of informal practices and regulatory failure in environmental governance. Meanwhile, Kumar and Agrawal (2000) investigated the economic costs of informality concerning renewable energy deployment and policy enforcement challenges in developing economies. The sharp increase in attention to these studies reflects a broader disciplinary convergence: economists highlighted the fiscal leakage from tax evasion in informal sectors, political scientists debated the governance implications of informality in environmental transitions, and legal scholars examined the effectiveness of environmental regulations under weak institutional conditions. This convergence elevated 2020 as a pivotal year in the literature on shadow economies and sustainability.

The 2008 spike (5.06 citations/year) aligns directly with van Ruijven et al. (2008), whose article garnered 91 citations, precisely matching the annual rate suggested by the cohort data. This paper remains a foundational reference for research linking energy transitions with economic structures.

2017 also shows a strong citation performance (4.07/year), bolstered by Awasthi and Li (2017), whose article has received 151 citations at a rate of 16.78 per year, indicating a rapidly growing influence within the field. The same trend is seen in Johnstone et al. (2017), whose 101 citations and 11.22/year reinforce the cohort's high impact.

Finally, Liu et al. (2020) and Wang et al. (2019) make significant contributions to their respective cohorts, with strong annual citation averages of 16.67 and 14.00, respectively, reflecting both the relevance and timeliness of their research focus.

Table 2. The top 10 high-impact papers related to interconnections of the shadow economy and developments of renewable energy, ranked by total citations

Source: Authors' analysis based on Biblioshiny App.

Title	TC	TC per Year	NTC
Mateo-Sagasta et al. (2015)	314	28.55	4.44
Awasthi and Li (2017)	151	16.78	4.13
Sharma and Jain (2020)	127	21.17	2.71
Kumar and Agrawal (2020)	118	19.67	2.52
Johnstone et al. (2017)	101	11.22	2.76
Liu et al. (2020)	100	16.67	2.13
Wang et al. (2019)	98	14.00	3.65
van Ruijven et al. (2008)	91	5.06	1.00
Cheng et al. (2014)	87	7.25	3.09
Walwyn and Brent (2015)	83	7.55	1.17

Table 3 summarizes the citation performance and bibliometric relevance of the ten most influential academic journals in the analyzed literature on the shadow economy and renewable energy.

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Table 3. Top 10 journals by local citation impact in the dataset

Source: Authors' analysis based on Biblioshiny App.

Source	h_index	g_index	m_index	TC	NP	PY_start
Environmental Science and Pollution Research	5	10	0.714	185	10	2019
Journal of Energy in Southern Africa	3	4	0.136	23	4	2004
Journal of Environmental Management	3	3	0.231	145	3	2013
Energy	2	3	0.222	68	3	2017
Energy Policy	2	2	0.1	45	2	2006
Energy Research & Social Science	2	2	0.222	21	2	2017
International Journal of Environmental Research and Public Health	2	2	0.25	59	2	2018
Renewable & Sustainable Energy Reviews	2	3	0.182	234	3	2015
Renewable Energy	2	3	0.154	38	3	2013
Sustainability	2	3	0.4	15	3	2021

Note: h-index – the journal's local h-index in the dataset; g-index – an index that gives more weight to highly-cited articles; m-index – the h-index divided by the number of years since the first publication in the source (local period); TC – total citations received by all documents from that source in the dataset; NP – number of publications; PY_start – the publication year of the earliest document from that source in the dataset.

The journal Environmental Science and Pollution Research stands out with the highest h-index (5), g-index (10), and total citations (185) from 10 documents published since 2019, giving it a high m-index (0.714). This shows both recent and impactful contributions, making it a significant hub of relevant research in the topic area.

Renewable & Sustainable Energy Reviews has the highest total citations per paper (78 on average across 3 papers) and a strong g-index (3), even though its h-index is 2. Its m-index of 0.182 suggests a steadily growing influence since its first publication in 2015.

Journals like the Journal of Environmental Management (h = 3, TC = 145) and Energy (h = 2, TC = 68) show good citation counts relative to their number of documents, indicating highly cited contributions, albeit with slightly older publication starts.

The Journal of Energy in Southern Africa, with an early PY_start of 2004, has had time to accumulate citations (TC = 23), though its m-index (0.136) and h-index (3) suggest more modest influence.

Newer contributors like Sustainability (first included in 2021) already show a promising m-index of 0.4, despite only three papers and lower total citations, suggesting fast-growing interest or relevance.

Table 4 represents the data according to Lotka's Law (seminal, Lotka, 1926; recently, Aytac et al., 2025) – the distribution of author productivity in the field of research concerning the interconnections between the shadow economy and renewable energy development.

Table 4. Lotka's Law in the field of research concerning the interconnections between the shadow economy and renewable energy development

Source: Author's analysis from Biblioshiny App.

Documents written	N. of Authors	Proportion of Authors
1	452	0.946
2	20	0.042
3	6	0.013

The data based on Lotka's Law reveal that most authors in the field of research on the interconnections between the shadow economy and renewable energy development are one-time contributors. Specifically, 94.6% of authors (452 out of 478) have written only one publication. A small portion, 4.2%, has contributed two publications, while only 1.3% have written three.

This pattern is consistent with Lotka's Law, which posits that most authors in a given field will publish only a single paper. At the same time, a progressively smaller number will produce multiple contributions (Lotka, 1926). Empirical studies across various disciplines, including bibliometric analyses of environmental science and renewable energy, have repeatedly confirmed this distribution (Aytac et al., 2025; Mongeon & Paul-Hus, 2016). The results suggest that although the topic attracts a broad range of researchers, sustained engagement is relatively limited. This may indicate that the field is either still emerging or characterized by interdisciplinary interest, drawing in authors from various domains like economics, energy policy, and sustainability who publish occasionally rather than consistently.

The prevalence of single-publication authors also indicates the opportunity for researchers to establish themselves as core contributors. With so few consistently active scholars, there is room for individuals or teams to take a leading role in shaping the research landscape. Overall, the distribution of author productivity reflects a field with broad interest but limited depth, where building a more stable and engaged scholarly community could significantly advance the discourse.

Table 5 presents a set of leading authors in the field of research exploring the interconnections between the shadow economy and renewable energy development, using key bibliometric indicators from Biblioshiny to assess their academic impact and productivity.

Table 5. Top 15 authors

Source: Authors' analysis based on Biblioshiny App.

Author	h_ index	g_ index	m_ index	TC	NP	PY_ start
Chu L.	3	3	0.75	72	3	2022
Von Blotttnitz. H.	3	3	0.158	38	3	2007
Ajide F.	2	2	0.5	40	2	2022
Brent A.	2	2	0.118	88	2	2009
Chen Y.	2	3	0.286	34	3	2019
Dada J.	2	2	0.5	40	2	2022
De G. J.	2	2	0.25	6	2	2018
Kowero G.	2	2	0.4	10	2	2021
Mutta D.	2	3	0.4	10	3	2021
Roos A.	2	3	0.4	10	3	2021
Shahbaz M.	2	2	0.667	72	2	2023
Wang G.	2	2	0.167	40	2	2014
Wekesa C.	2	3	0.4	10	3	2021
Yang X.	2	2	0.125	103	2	2010
Zhang J.	2	2	0.125	20	2	2010

The h-index and g-index reflect both the number of publications and their citation levels, indicating consistent and impactful authorship. The m-index helps to contextualize this impact over time by dividing the h-index by the number of years since the author's first publication in the dataset (represented by PY_start). This metric gives insight into how quickly an author's work gains recognition. TC stands for total citations, and NP for the number of publications.

Among the authors listed, Chu L. demonstrates an outstanding profile with an h-index and g-index of 3, and a notably high m-index of 0.75. This indicates not only that their work is cited frequently but also that it gained traction rapidly, within just a couple of years since their first publication in 2022. Similarly, Shahbaz M., whose first contribution came in 2023, already holds an m-index of 0.667 and 72 citations from just two papers, reflecting an immediate and strong influence.

In contrast, von Blotttnitz H. has been active since 2007 and has maintained a steady but gradual influence, with an h-index of 3, 38 total citations, and a lower m-index of 0.158 due to the longer time frame. Brent A., publishing since 2009, has the highest total citations among early contributors (88), but a lower m-index of 0.118, again reflecting a more cumulative rather than rapid citation pattern.

Authors such as Ajide F., Dada J., Mutta D., Roos A., and Wekesa C. also show promising recent productivity, with good m-index values (ranging from 0.4 to 0.5), indicating early and consistent recognition for their work published from 2021 onwards.

Others, like Yang X. and Zhang J., who began publishing in 2010, show high total citations (103 and 20, respectively), but relatively lower m-index values (0.125), suggesting a steady, long-term contribution without recent acceleration in impact.

The data show a mix of well-established contributors with cumulative influence and a newer cohort of authors whose work is receiving rapid attention. The high m-index scores of several recent authors highlight the growing relevance of this interdisciplinary field and suggest that new voices are quickly shaping the discourse on the shadow economy and renewable energy.

3.3. Geographical collaboration

Table 6 presents a country-level collaboration analysis of publications related to the interconnections between the shadow (informal) economy and renewable energy development, as generated by Biblioshiny.

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Table 6. Country-level collaboration analysis

Source: Authors' analysis based on Biblioshiny App.

Country	Articles	Articles %	SCP	MCP	MCP %
China	15	9.3	8	7	46.7
South Africa	15	9.3	13	2	13.3
The USA	13	8.1	11	2	15.4
India	11	6.8	11	0	0
The United Kingdom	7	4.3	6	1	14.3
Germany	5	3.1	2	3	60
Ghana	4	2.5	1	3	75
Vietnam	4	2.5	3	1	25
Australia	3	1.9	0	3	100
Malaysia	3	1.9	1	2	66.7
The Netherlands	3	1.9	2	1	33.3
Pakistan	3	1.9	2	1	33.3
Sweden	3	1.9	1	2	66.7

Note: Articles – total number of publications involving authors from that country; Articles % – the country's share of the total document corpus (in percentage); SCP – single country publications – publications authored solely by researchers from that country; MCP – multiple country publications – publications co-authored by researchers from multiple countries; MCP % – percentage of that country's total articles that are international collaborations.

China and South Africa lead the dataset with 15 articles each (9.3% of the total), but differ in collaboration patterns. China shows a balanced mix: 8 domestic-only publications and 7 international collaborations (MCP% = 46.7%), and South Africa, in contrast, has a much more domestic research focus, with only 2 of 15 publications involving international partners (MCP% = 13.3%).

The USA and India follow with 13 and 11 publications, respectively. The USA has a moderate international collaboration rate (15.4% MCP), while India has none (0%), suggesting a highly self-contained national research output in this field.

European countries like the UK and Germany show stronger tendencies toward collaboration. Germany has a high MCP% of 60, while the UK balances mostly domestic work (6 SCP) with some international engagement (1 MCP, or 14.3%).

Emerging economies such as Ghana (75%), Malaysia (66.7%), and Sweden (66.7%) show a firm reliance on international collaborations, which could indicate either capacity-building partnerships or access to external funding and networks.

Notably, Australia is unique in that all of its articles (100%) are co-authored internationally, indicating a strong global integration despite its low overall output (3 articles).

Source: Authors' analysis based on Biblioshiny App.

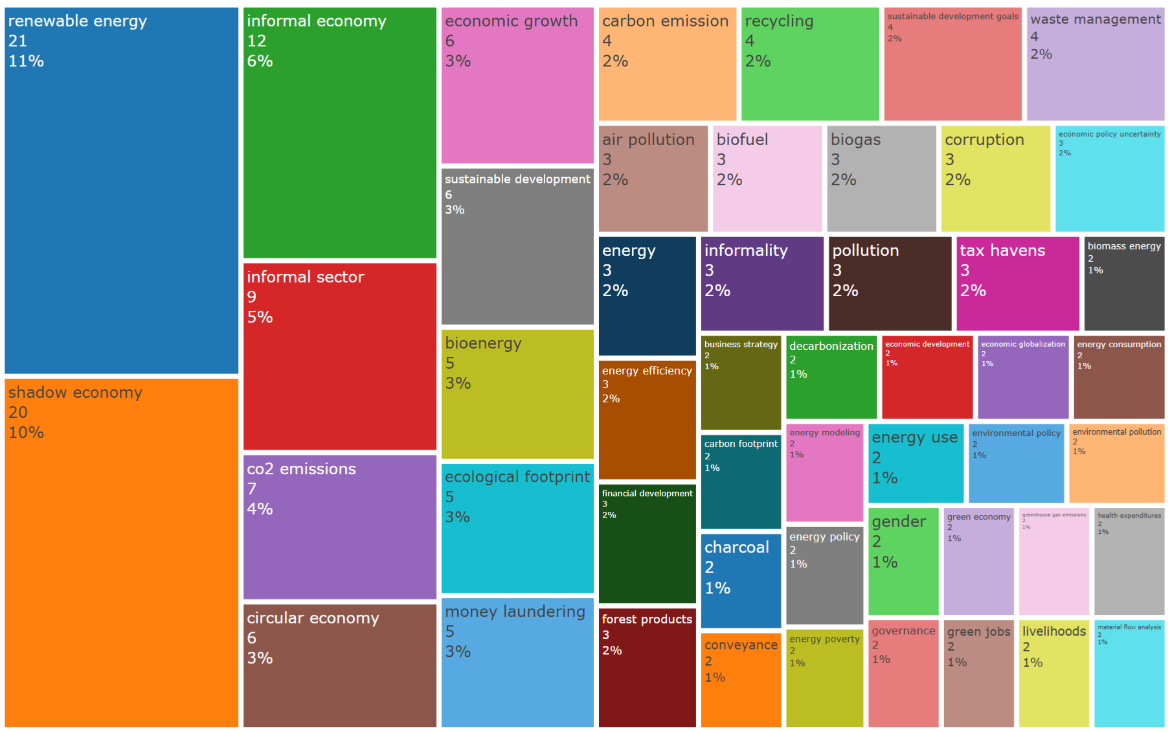

Figure 3. Tree map of the most frequent keywords

3.4. Keyword and thematic mapping

Figure 3 presents the Treemap visualization from Biblioshiny of the most frequent keywords used in documents analyzing the interconnections between the shadow (informal) economy and renewable energy development. Each block in the treemap represents a keyword (or thematic concept), and its size reflects the number of occurrences across the corpus. The percentage shown within each box indicates the keyword's share relative to the total number of keyword occurrences.

Notably, the authors' keywords were chosen as the basis for this visualization due to the higher metadata completeness in this field. According to the dataset's metadata quality report,

- only 29 records (18.01%) were missing authors' keywords,
- while 47 records (29.19%) were missing keywords plus (automatically generated terms based on references).

This made the authors' keywords a more complete and reliable set for analyzing thematic trends in the dataset.

The treemap highlights that "renewable energy" (11%) and "shadow economy" (10%) are the two dominant concepts, followed closely by "informal economy," "informal sector," and "CO2 emissions." Together, these form the conceptual core of the field. Supporting themes include economic growth, sustainable development, circular economy, and governance-related terms like corruption, money laundering, and tax havens. Sector-specific terms such as bioenergy, charcoal, and energy efficiency show how informality intersects with different energy technologies and environmental strategies.

This analysis provides a comprehensive thematic snapshot of how the scholarly community frames and connects issues of informality, sustainability, and energy transition, using terms explicitly chosen by the authors to reflect their research's core focus.

Figure 4 shows a co-occurrence network of keywords generated in Biblioshiny based on documents related to the interconnections between the shadow economy and renewable energy development. The visualization maps how frequently keywords appear in the same papers and how closely related their thematic clusters are within the research landscape. Each node represents a keyword, and the node's size reflects the frequency of that term across the dataset. The lines (edges) connecting nodes indicate co-occurrence – how often the connected keywords appear together. Color clusters group keywords that tend to co-occur more with each other than with other groups, indicating shared thematic spaces or subtopics.

Source: Authors' analysis based on Biblioshiny App.

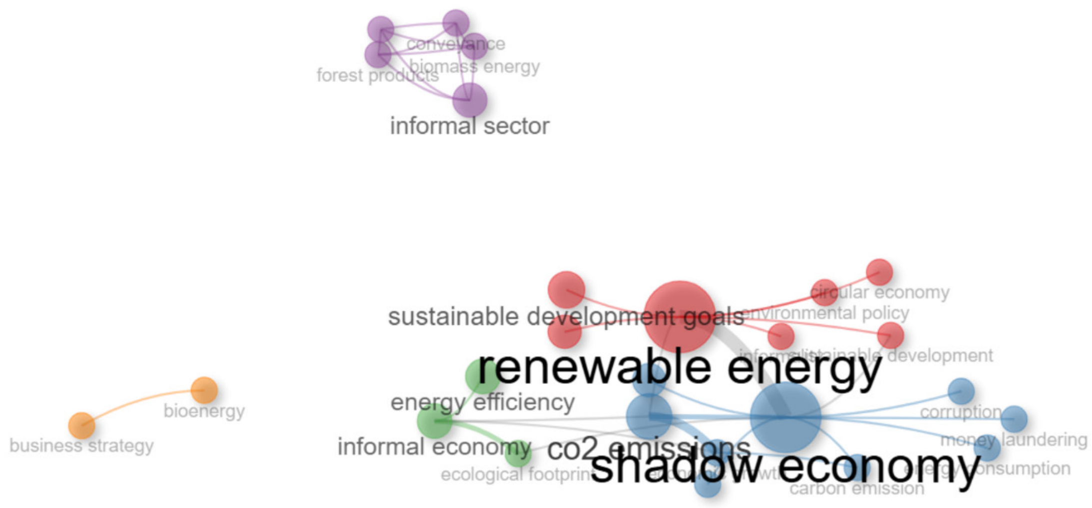

Figure 4. Co-occurrence network of keywords

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The most dominant terms in this network are "renewable energy" and "shadow economy," shown in bold and largest text, indicating their centrality in the analyzed literature. These two nodes are closely linked, confirming the focal nature of their relationship in this body of research.

Surrounding the central cluster are related terms such as "informal economy," "CO2 emissions," "ecological footprint," "energy efficiency," and "sustainable development goals." These keywords suggest that much of the research explores how informal or shadow economic activities influence environmental performance, especially carbon emissions and sustainability metrics.

Several smaller thematic clusters orbit the central network. For instance, in the top left corner, the purple cluster connects "informal sector," "forest products," "conveyance," and "biomass energy," possibly representing studies focused on informal bioenergy markets such as charcoal or timber. To the left, the orange cluster links "business strategy" and "bioenergy," likely pointing to management-focused discussions on integrating informal practices into formal energy frameworks.

A red cluster links "circular economy," "environmental policy," and "sustainable development," showing how governance, policy, and long-term goals intersect with renewable energy planning and shadow market behavior.

The blue cluster, connecting "corruption," "money laundering," and "carbon emission," represents research threads examining the darker institutional or governance aspects of informality about environmental performance.

This network shows that research on the shadow economy and renewable energy is multi-dimensional, combining themes like sustainability, governance, emissions control, informal labor, and natural resource use. It illustrates the central concepts and the research field's structure, emphasizing the topic's complexity and interdisciplinarity.

Figure 5 shows a thematic map generated by R Studio based on Biblioshiny's calculation of clusters and frequency of the keyword. That plots clusters of keywords based on their centrality (relevance to the overall field) and density (level of development within the topic). It is a strategic tool for understanding the structure and maturity of research themes in the literature on the shadow economy and renewable energy development. The map is divided into four quadrants, each representing a different category of thematic importance.

The thematic map confirms a mature, policy-salient core centered on renewable energy, shadow economy, and sustainable development goals in the upper-right ("motor themes"). Their simultaneous high centrality and density indicate that debates on clean-energy deployment are now tightly interwoven with questions of informality and governance. Near this core lie biofuel and carbon footprint, suggesting these topics are consolidating and increasingly connected to the main dis-

Source: Built by authors in R Studio based on analysis in Biblioshiny App.

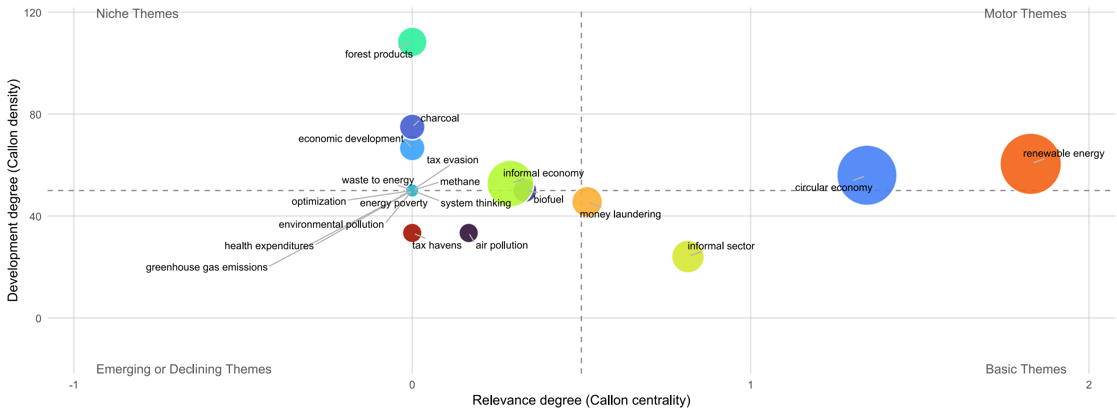

Figure 5. Thematic map of keywords

course. Compliance-focused items, such as money laundering, sit in the upper half of the right side, signaling well-developed sub-topics that are gaining relevance as the literature links illicit finance risks to energy-transition governance.

On the lower-right ("basic themes"), informal sector, informal economy, policy uncertainty, waste management/material flow analysis, energy, ecological footprint, and circular economy appear central but comparatively underdeveloped. These act as conceptual building blocks that the field is using widely but has not yet integrated into cohesive theoretical or methodological frameworks – prime candidates for deeper modelling and cross-country testing if they are to migrate into the motor quadrant. The upper-left ("niche themes") contains technically coherent but less central clusters (CO_2 emissions, economic growth, municipal solid waste, biogas/biomass energy, e-waste, livelihoods/consumption), which provide specialized lenses that could be better tied to informality mechanisms. The lower-left ("emerging/declining") is dominated by tax havens, highlighting an underexplored financial channel through which shadow activities may shape the cost of capital and investment flows in renewables. Together, the map suggests two immediate opportunities: to integrate illicit-finance and compliance perspectives more explicitly into energy-transition models, and to develop robust frameworks that connect circular-economy and waste-system analytics to the dynamics of the informal sector.

3.5. Relationship between the shadow economy and the development of renewable energy sources

Table 7 synthesizes how different scholarly studies have characterized the relationship between the shadow economy (SE) and the development of renewable energy sources (RES). Rather than presenting a unified conclusion, the literature reveals a diverse and sometimes contradictory set of findings, highlighting this intersection's complex and context-dependent nature. Each category reflects a different direction or interpretation of this relationship, supported by specific research.

Several studies support the position that SE decreases the development of RES. Authors like Anser et al. (2024), Dada et al. (2024), and Mateo-Sagasta et al. (2015), among others, argue that the shadow economy undermines clean energy prog-

Table 7. Synthesis of scholarly studies' findings about the relationship between the shadow economy (SE) and the development of renewable energy sources (RES)

Direction of relation	Supported research
SE decreases the development of RES	Anser et al. (2024), Asgar and Chauhan (2023), Castillo et al. (2024), Dada et al. (2024), Khurshid et al. (2024), Bofah et al. (2022), Bitzenis et al. (2018), Mateo-Sagasta et al. (2015), Duffy (2000), Chu et al. (2023), Chatterjee (2024), Sultana et al. (2022), Memduh Eren et al. (2022), Chen et al. (2021)
A complex, ambiguous relationship between SE and the development of RES may change over time or be different for different regions and conditions	Bobbins et al. (2023), Shahbaz et al. (2023), Chu and Hoang (2022), Knight (2013), Ward (2024), Gheraia et al. (2023), Kabir et al. (2022), Brown and McGranahan (2016)
SE increases the development of RES, especially in such areas as waste recycling	Ahad et al. (2021), Xie et al. (2022), Zhang and Razzaq (2022), Sena et al. (2022), Sepadi and Nkosi (2022), Samarasinghe et al. (2021), Apfel and Herbes (2021), Michel Devadoss et al. (2021), Canh et al. (2021), Liu et al. (2020), Prithiviraj and Chakraborty (2020), Chen (2018), Sola et al. (2019), Matinga et al. (2018), Hettiarachchi et al. (2018)
Development of RES (through intrinsic factors such as compassion and empathy, as well as extrinsic concerns for environmental sustainability, and transparency) can decrease SE share	Akinboade et al. (2023), Svazas et al. (2022), Romallosa and Kraft (2017), Nizami et al. (2017), Ghosh et al. (2006), Smit and Musango (2015), Eloundou et al. (2023), Abid et al. (2023), Finkelstein Shapiro and Nuguer (2024)
The development of RES can relate to a high share of SE through informal mining resources, waste sorting, etc.	Ballesteros et al. (2023), Wanjiru et al. (2018), Larwanou et al. (2023), Mutta et al. (2021), Cámara-Creixell and Scheel-Mayenberger (2018), Nkoana (2018), Deb and Sarkar (2017), Mateus et al. (2017), Thaba et al. (2015), Agarwal and Narain (1992), Acey and Culhane (2013), Couth and Trois (2012), Linzner et al. (2012), Benson et al. (2014)
There is no influence	Reid and Simatele (2021), Chen and Li (2021)
RES utilizes for AML	Marat (2015), Caneppele et al. (2013)

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ress. This may occur due to corruption, lack of regulatory enforcement, informal market distortions, and misallocating subsidies or resources, which can impede formal investment and technological scaling in the renewable energy sector.

Other researchers propose that the relationship between SE and RES is complex and ambiguous, varying across regions and over time. Studies by Bobbins et al. (2023), Shahbaz et al. (2023), and Knight (2013) reflect this viewpoint, indicating that under certain conditions, the informal sector might hinder RES development, while in other cases, it might play a complementary role, particularly in communities where formal infrastructure is weak or inaccessible.

A third group of works shows that SE can increase the development of RES, especially in areas like waste recycling and decentralized renewable energy solutions. Examples include Ahad et al. (2021), Zhang and Razzaq (2022), and Matinga et al. (2018). These studies highlight how informal actors often engage in practical, resource-based recycling, reuse, and small-scale renewable initiatives, particularly in developing or marginalized settings, thus contributing to environmental goals even without formal oversight.

Conversely, some research suggests that the development of RES can reduce the share of the shadow economy. Authors such as Akinboade et al. (2023) and Finkelstein Shapiro and Nuguer (2024) argue that clean energy technologies and policies, when implemented with transparency, social equity, and inclusive values, can foster formalization, reduce illicit practices, and promote broader socioeconomic integration.

In another line of inquiry, scholars like Wanjiru et al. (2018) and Eloundou et al. (2023) point out that RES development can be associated with an increased presence of SE, especially when renewable activities like charcoal production, informal waste management, and artisanal mining remain outside formal regulatory frameworks. In such cases, the expansion of green sectors can unintentionally entrench or expand informal economic practices.

Some studies, including Reid and Simatele (2021), report no significant influence between RES and the shadow economy, indicating that the connection may be negligible or unproven in some instances or contexts.

Finally, a small but noteworthy body of work, such as that by Marat (2015) and Caneppele et al. (2013), suggests that renewable energy systems may be exploited within anti-money laundering frameworks, pointing to a darker link where informal or illicit networks might manipulate green finance or subsidies.

This analysis shows that the relationship between the shadow economy and renewable energy is multifaceted and non-linear. Depending on context, sector, and implementation, the shadow economy can either constrain or support the development of renewables, while renewables themselves can help formalize or unintentionally support informal practices. This diversity of findings underscores the importance of nuanced, context-aware approaches in research and policymaking.

4. DISCUSSION

The bibliometric analysis provides critical insights into the evolving scholarly landscape surrounding the intersection of RES development and SE, particularly in the context of tax evasion and social responsibility. This discussion synthesizes those insights and juxtaposes them with the broader findings from existing literature to identify commonalities, divergences, and knowledge gaps.

The results confirm that academic interest in the interconnection between RES and SE has accelerated over the past two decades, with a noticeable surge in 2024. This trend aligns with observations from Abbasova (2023), Klavans and Boyack (2017), and Li and Hassan (2023), who all underscore increasing global research attention to sustainability, accountability, and economic governance. However, while literature points to significant growth in thematic exploration, our analysis reveals that collaboration, especially internationally, remains moderate. This finding corresponds with Prieto-Gutierrez et al. (2023), who noted the fragmented nature of interdisciplinary sustainability research.

The core keywords and thematic clusters identified in this study, namely "renewable energy," "shadow economy," "CO_2 emissions," and "informal sector", reinforce earlier bibliometric studies such as those by Krause et al. (2024) and Moroz and Lyeonov (2024), which emphasize the integration of energy policy with governance and fiscal regulation. Interestingly, the thematic map and co-occurrence network analysis in this study indicate that while these central themes are mature and interconnected, other important areas like "tax havens," "circular economy," and "policy uncertainty" remain either underdeveloped or peripheral. This confirms previous findings by Tran Viet and Phan Thanh (2024) and Dobrovolska et al. (2024b) that fiscal and regulatory complexity remains an under-explored domain in the clean energy transition.

The results also show that scholarly opinion is divided on the directionality of the RES-SE relationship. This aligns with the synthesis in Table 7, which captures six major viewpoints ranging from SE inhibiting RES growth (e.g., Mateo-Sagasta et al., 2015; Duffy, 2000) to RES helping reduce informality and improve social responsibility (e.g., Akinboade et al., 2023; Romallosa & Kraft, 2017). Our findings support the predominance of the first view, where a large shadow economy is seen as a constraint on renewable energy deployment due to reduced fiscal space, corruption, and regulatory avoidance, echoing earlier insights by Mazurenko et al. (2023) and OECD (2020).

However, the bibliometric clustering of keywords around themes like "waste management," "biomass," and "charcoal" also reflects perspectives from authors like Ahad et al. (2021) and Samarasinghe et al. (2021), who view the informal sector as an enabler in specific renewable niches –particularly in waste-to-energy and bioenergy systems. This duality mirrors the "complex and context-dependent" relationship identified by Shahbaz et al. (2023) and Chu and Hoang (2022), suggesting that geographic, institutional, and economic contexts must be considered when generalizing findings.

Furthermore, our analysis reveals that most contributions are one-off publications by individual authors, as shown by Lotka's Law application. This indicates a lack of sustained scholarly leadership in the field, a challenge also noted in broader bibliometric reviews by Onopriienko et al. (2023) and Samusevych et al. (2021). However, the concentration of productive authors like Chu L. and Shahbaz M. in recent years signals the emergence of a more stable academic core.

Finally, the presence of "corruption," "money laundering," and "governance" as secondary but significant keywords supports claims made by Dobrovolska et al. (2024b), Kuzior et al. (2022), and Caneppele et al. (2013), who highlight the risks of misuse and criminal infiltration in green sectors. These findings emphasize the importance of transparency and institutional oversight in ensuring that renewable energy transitions contribute to formalization rather than becoming new avenues for informal or illicit activity.

One key limitation of this article lies in its reliance on bibliometric methods, which, while effective for mapping trends and evaluating research output, do not capture the full depth or context of empirical findings within individual studies. The analysis is based solely on publications indexed in Scopus and Web of Science, potentially excluding relevant grey literature, policy papers, and region-specific studies not covered by these databases, particularly from developing countries where the shadow economy is most prevalent. Additionally, using metadata such as keywords and abstracts, rather than full-text content, may overlook nuanced or interdisciplinary insights that fall outside standard terminology. Finally, as a descriptive approach, bibliometric analysis cannot establish causal relationships or assess the practical effectiveness of renewable energy initiatives in addressing tax evasion or reducing informality. These aspects warrant further investigation through case studies, interviews, and mixed-methods research.

CONCLUSION

This study aimed to explore the intersection between the shadow economy and renewable energy development by examining how informal economic practices influence clean energy transitions and how renewable energy initiatives might contribute to economic formalization, fiscal transparency, and social

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responsibility. The study sought to illuminate trends, thematic directions, and knowledge gaps in this interdisciplinary research area, recognizing the growing policy and scholarly interest in achieving sustainable development alongside improved governance.

A systematic bibliometric analysis was conducted using 161 documents from Scopus and Web of Science. The study involved a combination of quantitative metrics and visual mapping tools from the Biblioshiny platform to assess publication trends, citation impact, author productivity, international collaboration, and keyword co-occurrence patterns. This methodology provided a structured overview of how the academic community has approached the link between shadow economies and renewable energy over time.

The findings reveal that research on this topic has experienced steady and accelerating growth, particularly since 2010, with a notable surge in 2024. The literature is conceptually diverse but anchored around core themes such as "renewable energy," "shadow economy," "informal sector," and "CO_2 emissions." Several dominant directions emerged: many studies conclude that the shadow economy hinders renewable energy development due to tax evasion, corruption, and regulatory gaps. Others point to complex or context-dependent relationships, and a minor but essential stream highlights the role of informal actors in advancing waste recycling and decentralized energy systems. Additionally, some research indicates that renewable energy can foster formalization and reduce informality by promoting transparency, employment, and social cohesion.

The bibliometric results indicate limited but growing international collaboration, with emerging economies playing a notable role. While the field remains relatively young and fragmented, the upward trend in citations and productivity indicates an increasing academic and policy relevance. Future research can build on this foundation by deepening conceptual frameworks, incorporating case-based empirical studies, and examining the bidirectional influence between informality and clean energy systems.

While this study provides valuable insights into the scholarly landscape connecting the shadow economy and renewable energy development, several limitations should be acknowledged. First, the analysis is limited to publications indexed in Scopus and Web of Science, which may exclude relevant grey literature or region-specific studies not covered by these databases. Second, the reliance on metadata (e.g., keywords and abstracts) may overlook nuanced discussions present only in the full text of articles. Lastly, as bibliometric methods focus on patterns and trends rather than causal relationships, this study does not assess the empirical validity of the findings reported in the literature. Future research could complement this approach with qualitative or case-based analyses to deepen contextual understanding.

AUTHOR CONTRIBUTIONS

Conceptualization: Serhiy Lyeonov, Alina Danileviča, Andreas Horsch.
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Formal analysis: Serhiy Lyeonov.
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Methodology: Serhiy Lyeonov, Andreas Horsch.
Project administration: Serhiy Lyeonov, Andreas Horsch.
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Writing – original draft: Serhiy Lyeonov, Alina Danileviča, Andreas Horsch.
Writing – review & editing: Serhiy Lyeonov, Alina Danileviča, Andreas Horsch.

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APPENDIX A

Search query:

TITLE-ABS-KEY (("shadow econom*" OR "informal econom*" OR "underground econom*" OR "grey econom*" OR "black econom*" OR "parallel econom*" OR "second econom*" OR "hidden econom*" OR "shadow sector*" OR "informal sector*" OR "underground sector*" OR "grey sector*" OR "black sector*" OR "parallel sector*" OR "hidden sector*")

AND

("renewable energy" OR "green energy" OR "hydropower" OR "pure pumped storage" OR "marine energy" OR "wind energy" OR "solar energy" OR "bioenergy" OR "biofuel" OR "mixed power" OR "bagasse" OR "biogas" OR "geothermal energy" OR ("onshore" AND "energy") OR ("offshore" AND "energy") OR ("battery storage" AND "energy") OR ("biomass" AND "energy") OR ("CSP" AND "energy") OR ("SPV" AND "energy")))

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