"Public interest and scholarly output on renewable energy and the shadow economy: Evidence from Google Trends and academic databases"

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PUBLIC INTEREST AND SCHOLARLY OUTPUT ON RENEWABLE ENERGY AND THE SHADOW ECONOMY: EVIDENCE FROM GOOGLE TRENDS AND ACADEMIC DATABASES

Abstract

Understanding the alignment between public interest and academic research is increasingly relevant in the context of global sustainability challenges. This study aims to investigate the relationship between societal attention, as measured by Google Trends, and scholarly output on renewable energy and the shadow economy. Using bibliometric data from Scopus and Web of Science alongside global Google Trends data from 2004 to 2025, the analysis employed Pearson and Spearman correlation coefficients, Granger causality, and distance correlation to assess the strength, direction, and form of association between public search trends and academic activity. The results reveal a significant Granger-causal relationship from public searches on "renewable energy" to academic publications, with F-statistics above 5.2 ($p < 0.01$), and strong positive correlations (Pearson $r = 0.72$; Spearman $\rho = 0.69$; distance correlation = 0.63). In contrast, the terms "informal economy" and "feed-in tariff" demonstrated weak or inconsistent associations, with correlations below 0.25 and statistically insignificant causality tests ($p > 0.1$). Cross-country comparisons further highlighted uneven alignment, with India showing high search intensity (Google Trends index > 75) but relatively low publication volume (< 2% of global output). At the same time, South Africa displayed closer coherence, with both indicators moving in tandem ($r \approx 0.61$). These findings underscore scholarly research's partial and asymmetric responsiveness to public demand, varying significantly by topic and geographic context. Moreover, while Google Trends offers robust signals of societal interest, disparities in digital access and literacy reduce its universality, pointing to critical underexplored research gaps with direct policy relevance.

Keywords	public interest, Google Trends, academic research, renewable energy, shadow economy, bibliometric analysis, correlation analysis
JEL Classification	Q42, O17, C82, D83

INTRODUCTION

The topic of public interest and scholarly output on renewable energy and the shadow economy is highly relevant in today's global context, where societies face mounting challenges related to sustainability, economic inclusion, and policy effectiveness. As governments and international organizations push for green transitions, understanding how informal economic structures intersect with renewable energy policies becomes essential for designing socially equitable and practically implementable solutions. The United Nations' Sustainable Development Goals (SDGS), particularly SDG 7 (Affordable and Clean Energy) and SDG 8 (Decent Work and Economic Growth), underscore the importance of expanding renewable energy while addressing informality in labor markets (UN, 2015). The IRENA also highlights in its reports that a just transition must consider the informal sector, which often

lacks access to formal energy systems and social protections. This evidences a growing recognition at the policy level that energy strategies must integrate economic inclusion.

The relationship between the shadow economy and renewable energy is complex and multifaceted. On the one hand, informal economic structures can obstruct the effective implementation of renewable energy policies by bypassing regulatory frameworks, reducing tax revenues, and fostering unequal access to energy resources. On the other hand, the informal sector often plays a crucial role in energy transitions by providing affordable, decentralized solutions in contexts where formal energy markets remain underdeveloped. For example, informal labor networks are frequently involved in producing, installing, and maintaining renewable technologies, particularly in rural and low-income regions. This dual role underscores the need for policies that expand renewable energy systems and formalize and support the contributions of informal actors, ensuring that energy transitions enhance sustainability and socio-economic inclusion.

UNESCO (2021) emphasizes the need for inclusive and responsive research systems that reflect societal concerns, highlighting the importance of aligning academic research with public awareness and demand. Additionally, the OECD (2020) underscores the significance of public engagement in shaping research and policy agendas. It provides empirical evidence on how deliberative processes can bridge the gap between public interest and academic research. Building on this policy and institutional context, the present study addresses a critical gap by empirically examining how public attention corresponds with scholarly activity in renewable energy and the shadow economy. Doing so contributes to debates on evidence-based policymaking, academic responsiveness, and the democratization of knowledge production within the broader sustainability agenda.

1. LITERATURE REVIEW

Understanding the interplay between public interest and scholarly output requires tracing how digital tools and bibliometric methods have evolved to capture societal concerns and academic responses. The increasing reliance on Google Trends and bibliometric mapping reflects a broader methodological shift towards quantifying public sentiment and aligning it with research agendas in sustainability, renewable energy, and informal economies.

Google Trends has become a recognized proxy for public interest, with early studies establishing its potential to track real-time societal attention across health, politics, and finance (Nuti et al., 2014; Mellon, 2013; Preis et al., 2013). Subsequent applications expanded into climate communication, sustainability, and behavioral responses to global challenges, demonstrating the tool's capacity to capture shifts in collective awareness (Dasandi et al., 2025; Erokhin & Komendantova, 2024). Recent analyses have illustrated its versatility, including tracking interest in smart cities, wartime education discourse, and the psychological impact of climate change, thereby highlighting its relevance for contexts where societal concerns rapidly evolve (Hrytsenko et al., 2024; Barvinok & Pudło, 2023; Moench, 2023; Yoder, 2019).

In parallel, bibliometric methods have matured into a robust framework for mapping research activity, identifying thematic clusters, and evaluating institutional or regional priorities. Foundational contributions have provided tools to assess topic prominence and intellectual structures within scientific production (Klavans & Boyack, 2017; Dobrovolska et al., 2024). Their use has since expanded to educational crises, retrenchment studies, renewable energy entrepreneurship, and real estate forecasting, illustrating their adaptability across disciplines (Artyukhov et al., 2024; Coffie & Onyinah, 2023; Myroshnychenko et al., 2024; Dobrovolska & Fenenko, 2024). Bibliometric evaluations have also supported investigations into financial fraud, wartime debt, healthcare disruption, and environmental health, underlining their relevance for both economic and social policy domains (Asare & Samusevych, 2023; Filatova et al., 2023; Didenko et al., 2023; Badreddine & Larbi Cherif, 2024; Matvieieva et al., 2023).

Digitalization and cybersecurity have emerged as prominent areas within bibliometric research, where analyses have captured threats, information forecasting, and innovation transfer in education and leadership trends in the post-COVID environment (Kuzior et al., 2021; 2022; 2024; Koibichuk et al., 2023; Zhavoronok et al., 2024). Alongside these developments, renewable energy has become a leading domain of bibliometric mapping, with research highlighting demand trends, entrepreneurship, and sector-specific challenges, including energy efficiency in residential contexts and Ukraine's post-war bioenergy transformation (Kuzior et al., 2021; Myroshnychenko et al., 2024; Sotnyk et al., 2023; Kurbatova et al., 2023; Samusevych et al., 2021). Studies have also explored the broader intersections of sustainability and geopolitics, artificial intelligence adoption in the social sciences, and business process management in organizational contexts (Ostapenko et al., 2023; Prieto-Gutierrez et al., 2023; Steiner et al., 2024; Koblianska et al., 2023).

The link between informal economies, taxation, and sustainable development is increasingly acknowledged within bibliometric work. Analyses demonstrate the coherence and tensions between tax systems and shadow economies, as well as the implications of managerial accounting and trade remedies for economic policy (Mazurenko et al., 2023; Abbasova, 2023; Tran Viet & Phan Thanh, 2024). Similarly, the wartime and post-war dimensions of economic security highlight the importance of aligning fiscal systems with governance frameworks (Filatova et al., 2023; Kovalov, 2024).

At the intersection of these strands, scholarship has begun to address the role of academic collaboration, ethics, and communication in ensuring that sustainability transitions reflect public needs and research evidence. University–industry partnerships, information dissemination, and sustainability reporting are highlighted as essential channels for bridging gaps between knowledge production and societal engagement (Samoilikova et al., 2023; Streimikiene et al., 2023; Ogutu et al., 2023; Correa Porcel et al., 2024). Broader studies of consumer and societal behavior reinforce these themes, demonstrating how energy awareness, generational purchasing patterns, and lifelong learning policies inter-

act with sustainability goals (Piwowarski, 2024; Li & Hassan, 2023; Onopriienko et al., 2023; Makarenko et al., 2023).

Taken together, the literature reveals a fragmented but increasingly connected landscape. Google Trends enables the observation of public engagement, while bibliometric methods provide insights into research priorities and gaps. Although renewable energy has gained substantial scholarly attention, the shadow economy remains underrepresented, and the intersection of the two themes has only recently emerged as an academic focus. This underscores the need for integrative approaches that bridge digital behavior, research output, and socioeconomic realities to strengthen the' relevance and inclusiveness of sustainability transitions.

This literature review explores how public attention, captured through tools like Google Trends, and scholarly research intersect, particularly in renewable energy and the shadow economy. The literature demonstrates increasing academic reliance on digital tools and bibliometric methods to assess trends, public sentiment, and research gaps.

This study aims to explore the relationship between academic publication trends and public search interest regarding the shadow economy and renewable energy, exploring the responsiveness and directional influence between scholarly activity and societal engagement.

2. METHODOLOGY

2.1. Data collection

2.1.1. Scopus and Web of Science databases

Two academic databases, Scopus and Web of Science (WoS), were selected for their extensive and multidisciplinary indexing of peer-reviewed literature. These databases comprehensively cover relevant fields such as economics, energy policy, environmental studies, and social sciences, ensuring the quality and relevance of sourced articles.

A detailed Boolean search query was constructed to identify literature discussing intersections between the shadow economy and renewable energy.

The query accounted for varied terminologies and synonyms across both domains. Appendix A presents the Boolean expression applied to both databases' titles, abstracts, and keywords fields.

Inclusion and Exclusion Criteria. The search results were refined using the following inclusion criteria: types of documents (articles, conference papers, books, and book chapters). No restrictions were placed on languages, countries, or access type (open access).

The initial search yielded 222 documents (119 from Scopus and 103 from WoS). After eliminating duplicates and screening titles and abstracts for relevance, 161 articles remained for comprehensive full-text review and thematic analysis.

2.2. Google Trends

In the digital era, tools like Google Trends offer novel insights into societal concerns, making exploring whether academic research aligns with, or lags, public awareness and demand increasingly important. According to Google's official Google Trends Help Centre (n.d.), Trends data reflects what people are searching for on Google in real time and over long periods, making it helpful in identifying shifts in public interest across regions and topics. Google emphasizes its value in understanding broad patterns of interest, especially during major events or societal changes, demonstrating its utility as a proxy for public concern. For example, Yoder (2019) noted that during major climate protests, searches for "climate change" on Google surged to record highs, even exceeding those for widely followed pop culture topics like "Game of Thrones." This illustrates how global events can trigger sharp increases in public interest in environmental issues. Similarly, Moench (2023) reported in *Time* that between 2018 and 2023, worldwide searches for terms such as "climate anxiety" and "eco-anxiety" rose by 4,590%, highlighting a significant rise in public concern about climate-related challenges.

Monthly Google Trends data for search terms "informal economy," "renewable energy source," and "feed-in tariff" (worldwide) from 2004 to 2025 were collected. To facilitate annual comparative analysis, monthly data were aggregated by year.

The monthly dataset was imported, standardized to date format, and the year was extracted. Subsequently, the data were grouped by year, and the average interest per term was calculated, providing an annual overview suitable for analyzing trends over the studied period.

To transform monthly Google Trends data into annual data, an aggregation process by year was applied. Initially, the dataset containing monthly interest values for selected search terms was imported, and the date column was converted to a standard date format. The year was then extracted from each date entry using date-handling functions. Subsequently, the data were grouped by year, and the average interest value for each term was calculated across all months within the same year. This aggregation provides a simplified yearly overview of search interest trends, facilitating easier comparison and analysis over time.

While Google Trends provides valuable insights into online public interest, its use as a proxy for societal attention remains an assumption rather than a direct reflection of reality. Search data captures only the behavior of internet users. However, a considerable portion of the global population either has limited access to the internet or does not use it at all. Consequently, genuine interest in renewable energy or concerns related to the shadow economy may be underrepresented in Google Trends, particularly in regions where offline engagement is vigorous but digital activity is weak. Furthermore, in less developed countries where internet infrastructure is scarce or absent, public interest cannot be adequately measured through online search volumes, despite these issues being highly relevant in their socio-economic context. Therefore, while Google Trends offers a practical and dynamic measure of online engagement, it must be interpreted cautiously and considered alongside these inherent limitations.

2.3. Data analysis

Data analysis involved several statistical techniques. Pearson and Spearman correlations were calculated to examine linear and monotonic relationships between the number of academic articles and Google search interest trends. Additionally, Granger causality tests assessed directional pre-

dictive relationships, evaluating whether search interest in specific terms could predict subsequent changes in publication counts. Distance correlation was employed to identify potential nonlinear relationships. These analyses were performed using statistical software R Studio, and results were visualized through scatterplots with LOESS smoothing curves to clarify the observed trends and associations.

3. RESULTS

Figure 1 offers a comparative view of academic publication activity on renewable energy and the shadow economy, as well as public search interest over time (1984–2024) for the informal economy, renewable energy, and feed-in tariffs.

The trend in several published articles on the informal economy and renewable energy sources represents academic interest.

The dark blue line in the plot illustrates the number of academic articles published annually on the combined topics of the informal economy and renewable energy sources. From 1984 to 1999, the number of publications remained minimal, with zero or one article per year, indicating limited scholarly engagement. However, starting in 2000, a notable upward trend began to emerge.

This growth in academic output is well-described by an exponential function:

$$y = 0.6385 \cdot e^{0.1316x}, \tag{1}$$

where x represents the number of years since 2000, the coefficient of determination $R2 = 0.9057$ indicates a firm fit, meaning over 90% of the variation in publication counts can be explained by this exponential model. This suggests that scholarly attention toward the intersection of informal economies and renewable energy is not just increasing but doing so at an accelerating pace.

Source: Authors' calculation in R Studio and Excel.
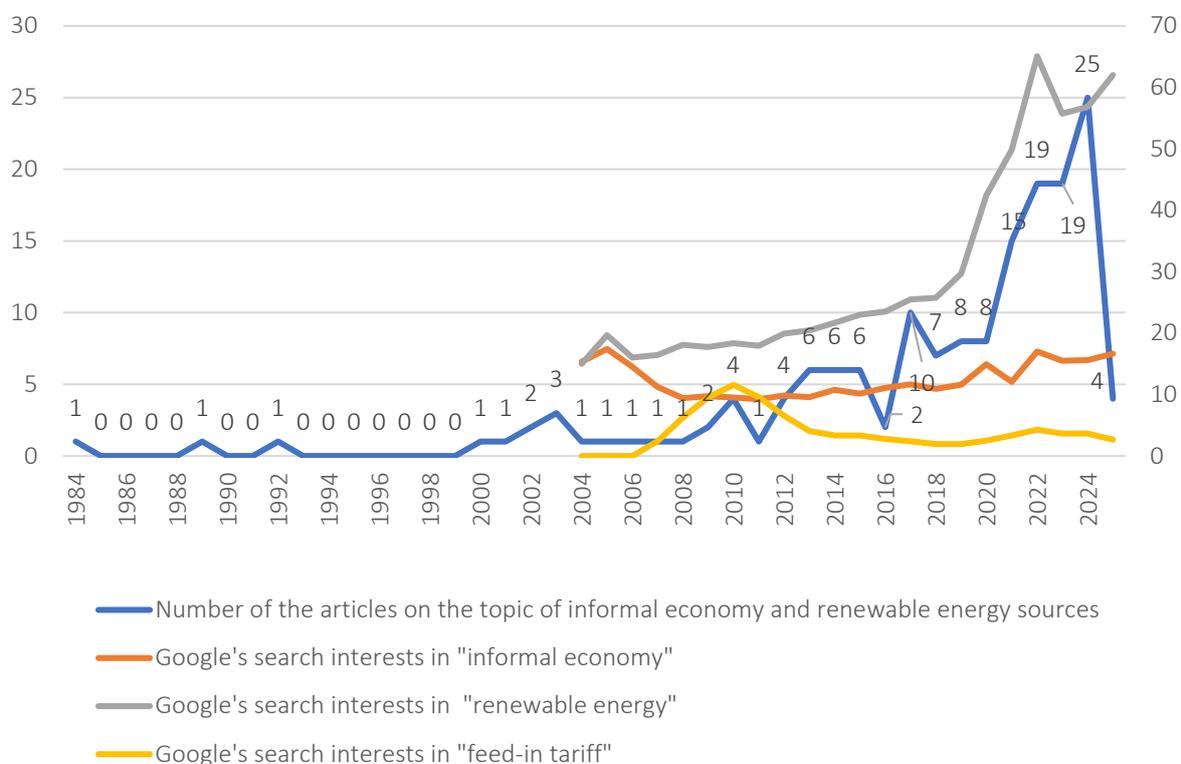

Figure 1. The levels of academic publication activity on renewable energy and the shadow economy over time (1984–2024), and search interest for the informal economy, renewable energy, and feed-in tariffs over the period 2004–2024

The exponential nature of the trend implies that these topics are becoming increasingly relevant in the academic discourse, potentially driven by mounting global concerns over sustainability, green transitions, and inclusive economic policies. The peak in 2023 (25 articles) reinforces this acceleration, aligning with broader societal and political momentum on energy justice and climate policy.

The orange line, representing Google search interest in the term "informal economy", became visible around 2004 and exhibits a moderate yet stable trajectory over time. While minor fluctuations mark a slight upward trend, overall public curiosity toward this term remains limited compared to others.

In contrast, the green line, corresponding to the search interest in "renewable energy", demonstrates a consistently strong and growing public engagement. Beginning around 2004, this interest intensified notably after 2015, reaching its peak in 2023. This trend closely aligns with the global policy shift toward climate action and renewable energy investment, including implementing international frameworks such as the Paris Agreement.

The light blue line, representing searches for "feed-in tariff", shows comparatively lower levels of public interest. Emerging after 2007, it featured minor peaks between 2011 and 2014, followed by a gradual decline. This suggests that "feed-in tariff" remains a more technical or niche term, less prominent in general public discourse.

Several key insights emerge from this comparison. Firstly, public interest appears to precede academic output, particularly in the case of "renewable energy". Search interest in this topic rose steadily from 2005 to 2015, whereas the number of related academic publications increased significantly only after this period. This may indicate that scholarly engagement is responsive to shifts in public and policy-driven attention.

Secondly, there is a noticeable mismatch in the popularity of search terms. "Renewable energy" consistently attracts higher public interest than either "informal economy" or "feed-in tariff", yet academic research often seeks to integrate these topics, potentially reflecting efforts to explore the intersection of green transitions with informal labor markets and economic inclusion.

Finally, the acceleration of research activity after 2015 may correspond to the growing influence of global sustainability agendas, such as the Sustainable Development Goals. This pattern highlights the increasing academic momentum in addressing complex, interdisciplinary issues at the nexus of environment, economy, and society.

The correlation plot (Figure 2) visually illustrates the linear relationships between academic publi-

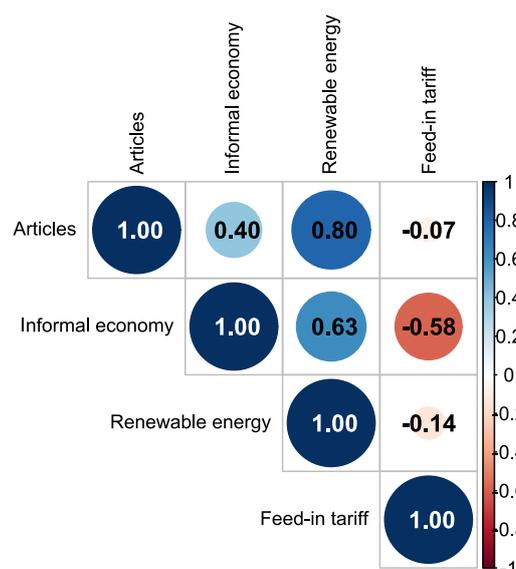Source: Authors' calculation in R Studio.

Figure 2. Correlation plot

cation activity and public interest in three thematic areas: "informal economy," "renewable energy," and "feed-in tariff."

The number of published articles, represented by the variable Number of articles on the topic of informal economy and renewable energy sources, shows a strong positive correlation (r = 0.80) with public Google's search interests in renewable energy, suggesting that scholarly output in this area tends to rise in parallel with growing public engagement. The p-value is extremely small, < 0.0001, indicating a highly statistically significant result. The 95% confidence interval ranges from 0.5704 to 0.9134, which does not include zero, providing strong evidence of a meaningful and positive relationship between the two variables. This alignment may indicate that academic research is responsive to broader societal and policy-driven attention surrounding renewable energy.

In contrast, the relationship between the number of articles and interest in the informal economy is moderate (r = 0.40), implying a weaker but still present connection between public discourse and scholarly activity. However, the p-value is 0.06792, slightly above the conventional 0.05 threshold for statistical significance. This means that while a trend may suggest a relationship, the evidence is insufficient to confirm it statistically. The 95% confidence interval ranges from −0.0305 to 0.7008, which includes zero, further suggesting that the correlation might not be reliable.

The correlation between article output and public interest in feed-in tariff is negligible (r = −0.07), reflecting little to no direct association. This may be due to the term's technical specificity and limited resonance with broader audiences. The p-value is 0.7418, which is relatively high, showing that the result is not statistically significant. The confidence interval ranges from −0.4810 to 0.3584

and includes zero, reinforcing the conclusion that there is no evidence of a meaningful relationship between these variables.

Notably, a moderate negative correlation (r = −0.58) between search interest in the informal economy and feed-in tariff suggests that these topics may be the focus of attention during different time periods or within distinct public or policy contexts. The analysis highlights that public interest in renewable energy is the most influential factor among the three in relation to academic production. In contrast, the informal economy has a more modest connection, and feed-in tariffs appear to operate independently from both scholarly and widespread public attention.

The next step is exploring causal inference or lag analysis, particularly to examine whether changes in Google search interests *cause* changes in the number of articles (see Table 1).

The high p-value for informal economy interest and feed-in tariff interest indicates no evidence that search interest in "informal economy and "feed-in tariff" Granger causes the number of articles on the topic of informal economy and renewable energy. So far, "informal economy" does not Granger-cause the number of articles published on the topic of informal economy and renewable energy, regardless of lag length.

A powerful and statistically significant result for renewable energy interest suggests that past search interest in "renewable energy" Granger causes changes in publication activity. In other words, public attention to renewable energy (as measured by Google Trends) appears to predict or possibly influence the number of articles published on the topic of informal economy and renewable energy. Search interest in "renewable energy" correlates with but precedes increases in article production

Table 1. Outputs of the Granger causality tests for article count for each variable of the three Google search interest terms

Source: Authors' calculation in R Studio.

| Variable	Lag 1		Lag 2		Lag 3	
	F-statistic	p-value	F-statistic	p-value	F-statistic	p-value
Informal economy interest	0.0598	0.8096	0.1217	0.8863	2.0664	0.1583
Renewable energy interest	16.349	0.0008	8.2535	0.0038	19.762	< 0.0001
Feed-in tariff interest	0.0297	0.865	0.0391	0.9617	0.6578	0.5935

on the topic across multiple lag lengths. This suggests a robust, temporally consistent predictive relationship, adding credibility to a causal narrative (at least in the Granger sense).

The results of the reversed Granger causality test show that the number of articles (y1) does not Granger-cause Google search interest in "renewable energy" ($x2$). At a one lag, the F-statistic is 0.205 with a p-value of 0.6561, indicating no significant relationship. Increasing the lag to two yields an even weaker result, with a p-value of 0.9075. At lag three, the F-statistic increases slightly to 1.9669, but the p-value remains nonsignificant at 0.1728. These outcomes consistently suggest that y1 does not help predict future values of x2.

In contrast to earlier findings where $x2$ significantly Granger-caused y1 across multiple lag lengths, this direction shows no evidence of predictive power. The implication is that the relationship is one-directional: rising public interest in renewable energy appears to lead, rather than follow, increases in article production on the topic. This supports the interpretation that public attention may be a driving factor behind the surge in scholarly or media content rather than a reaction to it.

Figure 3 visually compares scientific publication activity (number of articles) with public interest (Google search trends) in three key terms ("informal economy," "renewable energy," and "feed-in tariff") across multiple countries. The sample

Source: Authors' calculation in R Studio and Excel.
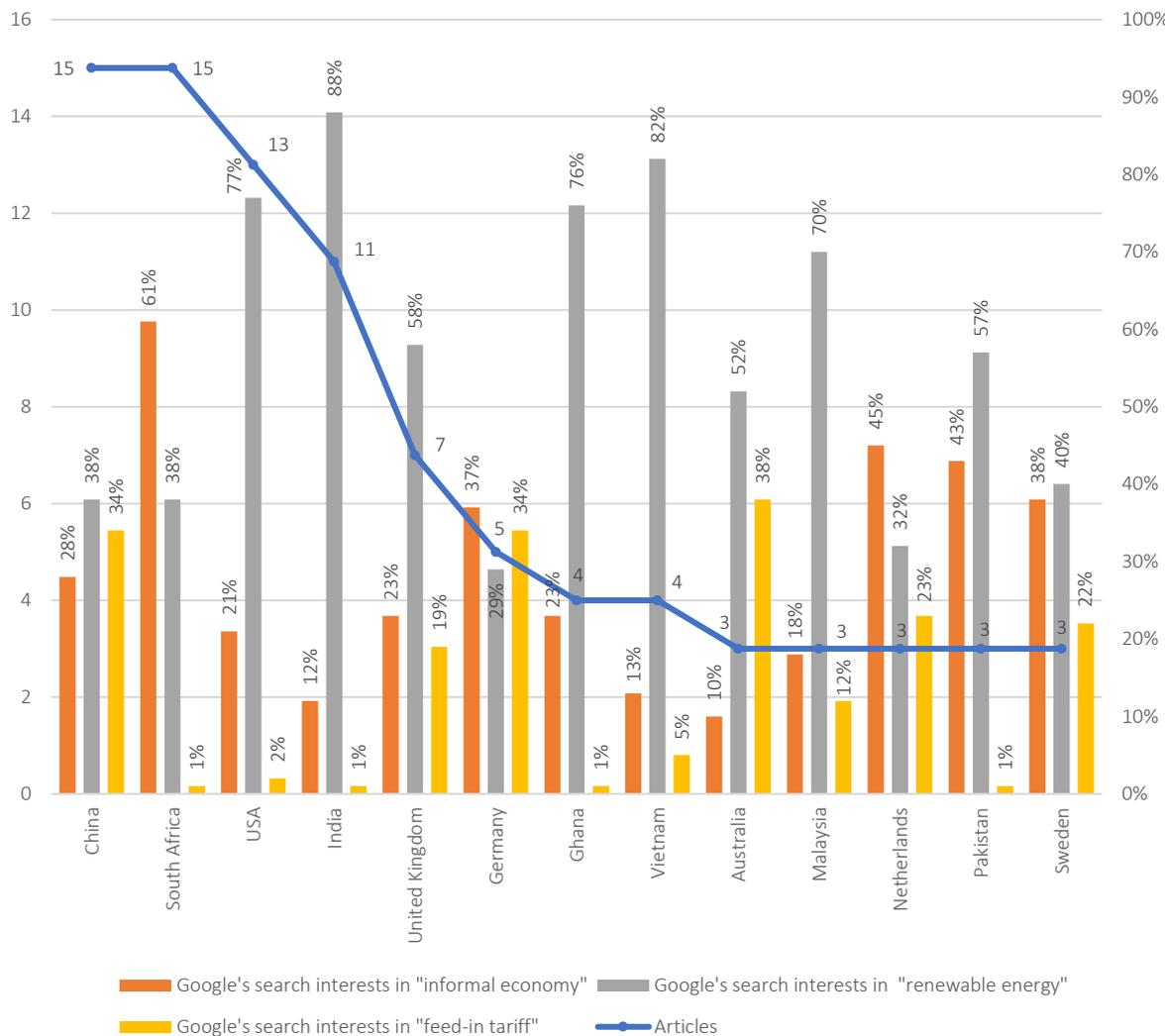
Note: * (Google search trends) in three key terms – "informal economy," "renewable energy," and "feed-in tariff" across the top 13 countries according to the number of publications (3 or more).

Figure 3. Comparing the scientific publication activity (number of articles) with the public interest*

Table 2. Outputs of the Pearson correlation test between article counts and the three Google search interest terms

Source: Authors' calculation in R Studio.

Variable	Correlation coefficient (r)	p-value	95% CI
Informal Economy Interest	−0.0837	0.5981	[−0.378, 0.226]
Renewable Energy Interest	0.236	0.1331	[−0.074, 0.503]
Feed-in Tariff Interest	< 0.0001	1	[−0.304, 0.304]

of countries includes ones where authors affiliated with national institutions have published at least three scientific articles on renewable energy and the shadow economy within the observed period. This threshold was applied to ensure that only countries with a consistent level of academic contribution were represented, allowing for a more meaningful comparison across contexts. Importantly, all of the countries included in this figure also demonstrate measurable public interest in the analyzed Google Trends terms ("renewable energy," "informal economy," and "feed-in tariff"). This parallel presence of both scholarly activity and search-based public engagement highlights a shared relevance of the topics across diverse national settings, even though the intensity and balance between academic output and public attention vary considerably from country to country.

China has the highest number of articles (15) and moderate public interest in all three terms, suggesting vigorous research activity with average public engagement. South Africa also has 15 articles but shows significantly higher interest in the informal economy (0.61), which indicates a better alignment between societal concern and academic research. On the other hand, India shows very high public interest in renewable energy (0.88) but has fewer articles (11), pointing to a gap between public awareness and research output. This suggests opportunities for academic focus to match public demand.

In the United States, public interest in renewable energy is high (0.77), and the article count is also strong (13), reflecting both public engagement and research attention on this topic. The term "feed-in tariff" tends to receive lower public interest overall, with most countries scoring below 0.2. An exception is Japan, which has a relatively high interest rate (0.47), which may be due to the relevance of national energy policy or local discourse.

These data also help identify where further research or policy engagement may be needed. Countries

with high public interest but low research output, such as those with intense concern for the informal economy or renewable energy but fewer publications, may benefit from capacity-building or increased academic investment. Similarly, when academic activity is high but public interest is low in some high-income countries, this may suggest a disconnect between scholarly work and societal relevance.

The outputs of the Pearson correlation test between article counts and the three Google search interest terms are presented in Table 2.

Across all three comparisons, the Pearson correlation results indicate no statistically significant relationships between scientific publication output and public interest, as measured by Google search trends. The correlation between article counts and search interest in the informal economy is weak and negative. In contrast, the relationship with renewable energy interest is weakly positive but still insignificant. In the case of feed-in tariffs, there is essentially no correlation. These findings suggest a possible disconnect between what the public is interested in and what is published in academic research on these topics. It is also possible that other factors, such as national policy priorities, research funding, or academic infrastructure, play a more substantial role in determining publication activity than public interest alone.

The results of Spearman's rank correlation tests, which assess whether there is a monotonic relationship between article output and public search interest in each topic, are presented in Table 3.

For the correlation between article counts and search interest in the "informal economy", Spearman's rho is −0.175, indicating a weak negative relationship. The p-value is 0.2664, which is not statistically significant. This means no clear monotonic trend exists between the number of articles and public interest in this topic across countries.

Table 3. Outputs of Spearman's rank correlation tests between article counts and the three Google search interest terms

<div align="right">Source: Authors' calculation in R Studio.</div>

Variable	S	Correlation coefficient (rho)	p-value
Informal Economy Interest	14,506	−0.175	0.2664
Renewable Energy Interest	9,734.4	0.211	0.1794
Feed-in Tariff Interest	10,411	0.156	0.3226

For the correlation between articles and "renewable energy" search interest, the rho is 0.211, showing a weak positive relationship. The p-value is 0.1794, which is also not statistically significant. While there might be a slight trend where higher search interest aligns with more research output, the evidence is insufficient to confirm it statistically.

For "feed-in tariff", the rho is 0.156, another weak positive correlation. The p-value is 0.3226, which again means the relationship is not statistically significant.

None of the relationships between publication output and public interest in these topics show statistically significant monotonic patterns. The weak correlations suggest that country-level public interest does not consistently align with the number of articles published on these topics. This reinforces the earlier observation that different factors may drive public attention and research activity or that there are barriers limiting alignment between them.

Unlike Pearson or Spearman, distance correlation (Table 4) detects any dependency – linear, non-linear, monotonic, or more complex relationships. A distance correlation of 0 means complete independence, while values closer to 1 indicate stronger dependence (of any kind).

The distance correlation between article counts and search interest in the informal economy is 0.2615, indicating a weak to moderate relationship.

However, the p-value is 0.334, which is not statistically significant. This suggests that the observed association could be due to chance, and there is no firm evidence of a meaningful dependency between these variables.

For renewable energy interest, the distance correlation is 0.2938, the strongest among the three topics, and points to a moderate non-linear association. The p-value is 0.17, which is also not statistically significant but closer to the typical significance threshold of 0.05. This suggests a possible trend where higher public interest in renewable energy may be associated with more research output. However, the evidence is insufficient to confirm this relationship with confidence.

Regarding feed-in tariff interest, the distance correlation is 0.1672, which reflects a weak relationship. The p-value is 0.796, indicating that the observed association is highly likely to have occurred by chance. This result shows no evidence of any real connection between public interest in feed-in tariffs and the number of related scientific articles.

Among the three topics, renewable energy shows the strongest (though still non-significant) association between public interest and research output. The informal economy shows a weak and statistically non-significant pattern, and the fe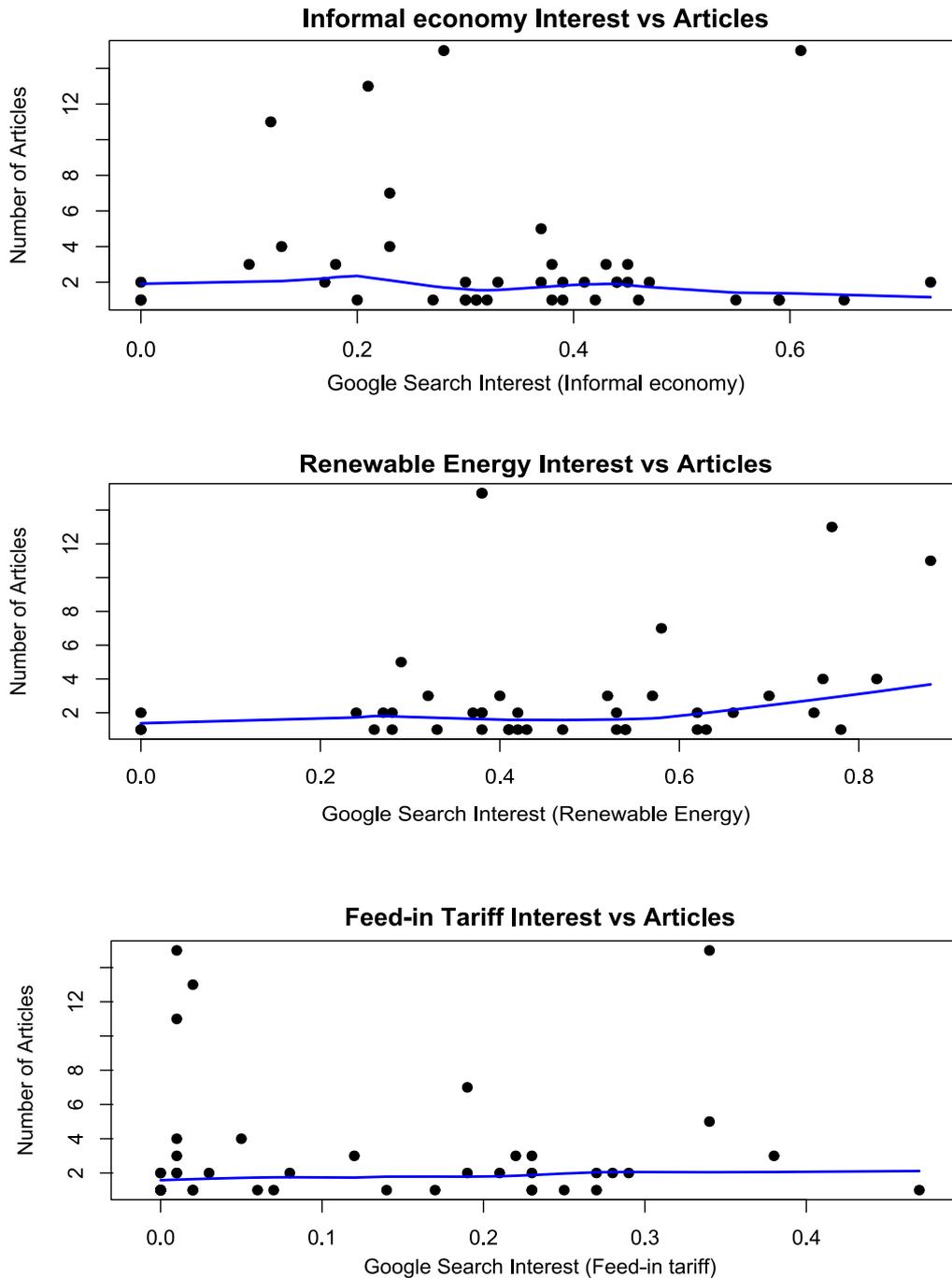ed-in tariff shows virtually no relationship. Figure 4 presents three scatterplots with smooth LOESS curves to visualize the relationships between public search interest (Google Trends) and the number of scientific articles for each topic.

Table 4. Outputs of Distance Correlation (dCor) between article counts and Google search interests

<div align="right">Source: Authors' calculation in R Studio.</div>

Variable	dCov	dCor	p-value	dVar(X)	dVar(Y)
Informal Economy Interest	0.1237	0.2615	0.334	2.0540	0.1089
Renewable Energy Interest	0.1553	0.2938	0.17	2.0540	0.1361
Feed-in Tariff Interest	0.0758	0.1672	0.796	2.0540	0.1001

Figure 4. Scatterplots with smooth LOESS curves to visualize the relationships between public search interest (Google Trends) and the number of scientific articles on the interrelations of renewable energy and the shadow economy

The calculation findings align with the visual plots and suggest that public engagement (via search trends) is not a consistent predictor of academic research activity but may be more relevant in the case of renewable energy.

The results presented in this study directly contribute to fulfilling the research aim: understanding the interplay between public interest and academic research concerning the shadow economy and renewable energy. By employing statistical

methods such as Pearson and Spearman correlations, Granger causality tests, and distance correlation, the analysis uncovered important patterns that link societal engagement, measured through search behavior, to scholarly attention in this interdisciplinary domain. The results confirm that the research aim has been achieved – the study successfully demonstrates that public interest, particularly in renewable energy, plays a measurable and potentially directional role in academic research trends. This insight provides a valuable foundation for further exploring how public sentiment can inform, influence, or even predict the focus and evolution of scholarly inquiry in critical areas of social and environmental importance.

4. DISCUSSION

The findings of this study align with and expand upon a growing body of literature exploring the relationship between societal interest and academic engagement, particularly in the fields of renewable energy and the informal economy. The statistical analyses confirm that public search interest in "renewable energy" significantly Granger-causes an increase in related academic publication output, suggesting a temporal precedence where public concern drives scholarly attention. This aligns with prior work by Preis et al. (2013) and Dasandi et al. (2025), who identified Google Trends as a powerful tool for gauging shifts in public interest and its predictive potential across various domains, including climate and financial markets.

The strong correlation between search volume for "renewable energy" and publication activity is consistent with the conclusion of Nuti et al. (2014), who argued that online search behavior is a proxy for public awareness, particularly during heightened societal discourse. In contrast, the limited influence of "informal economy" and "feed-in tariff" interest on scholarly output, as demonstrated through correlation and Granger causality tests, indicates a more fragmented or delayed academic response to these themes. This echoes findings by Samoilikova et al. (2023), who emphasized the underrepresentation of informal economic structures in sustainability discourse, despite their significant real-world implications.

While studies like those by Erokhin and Komendantova (2024) and Kurbatova et al. (2023) highlighted growing attention to climate narratives and green transitions, the weak statistical relationships between public search interest in "feed-in tariff" and academic engagement suggest that technical policy instruments may fail to resonate with broader public discourse. This divergence may explain the negligible public engagement observed in your data, reinforcing that effective communication strategies are essential for translating policy into public relevance (Streimikiene et al., 2023).

Moreover, country-level disparities in alignment between public interest and academic output further support the arguments of Dobrovolska et al. (2024) and Myroshnychenko et al. (2024), who found that academic productivity is unevenly distributed and often constrained by national research infrastructure and funding environments. The case of India, which has high public engagement but fewer publications, illustrates this disconnect. Conversely, South Africa's alignment between interest in the informal economy and academic output supports the relevance of place-specific priorities. It supports findings by Mazurenko et al. (2023) on the importance of tailoring research agendas to socio-economic realities.

Notably, the exponential growth in academic publications on the intersection of renewable energy and the shadow economy since 2000 reinforces the conclusions of Klavans and Boyack (2017), who argued that emerging interdisciplinary topics tend to exhibit rapid acceleration once they gain prominence. However, as indicated by distance and Spearman correlation results, this growth is not uniformly associated with public attention across all related themes, which suggests that external factors such as international policy frameworks (such as the SDGs) and institutional funding priorities may also play a decisive role in shaping research output.

Additionally, the broader methodological landscape provided by bibliometric studies (e.g., Prieto-Gutierrez et al., 2023; Artyukhov et al., 2024) affirms the relevance of tracking academic discourse as a dynamic process responsive to external stimuli. However, the observed one-directional Granger causality relationship – where public interest predicts research activity, but not vice versa – indicates that academia may often follow rather than lead societal

discourse. This contradicts the traditional model of research informing public awareness and instead supports a feedback loop in which public engagement triggers deeper academic exploration.

5. LIMITATIONS

While this study offers valuable insights into the relationship between public interest and academic research on renewable energy and the shadow economy, several limitations should be acknowledged.

First, relying on Google Trends as a proxy for public interest presents particular challenges. Although it provides a practical, accessible measure of general online attention, it does not account for demographic, regional, or socioeconomic variations in internet access and search behavior. As such, the data may disproportionately reflect the interests of internet users in more developed or digitally connected regions, potentially skewing interpretations of global public concern.

Second, while rigorous, using publication counts from Scopus and Web of Science as indicators of academic activity does not capture the full breadth of scholarly engagement. Important contributions in non-indexed journals, policy reports, working papers, and grey literature are excluded, which may limit the comprehensiveness of the academic landscape described.

Third, the search query, though carefully constructed to include a wide range of synonymous and related terms, may still miss relevant publications due to variations in terminology or interdisciplinary framing. Similarly, by focusing only on articles that mention the shadow economy and renewable energy, the study may exclude relevant literature that discusses these themes separately but in related contexts.

Fourth, while Granger causality tests provide valuable insights into temporal precedence and predictive relationships, they do not confirm true causality. The observed correlations between public search interest and academic output should thus be interpreted as suggestive rather than definitive evidence of influence.

Finally, the study's time frame, constrained by the availability of Google Trends data (beginning in 2004), limits the historical perspective. The analysis does not capture earlier developments in the academic discourse and public policy surrounding renewable energy and informal economies.

These limitations point to opportunities for future research, including more granular analysis using regional or country-level data, additional data sources beyond search trends and indexed articles, and the exploration of qualitative insights to complement the quantitative findings presented here.

CONCLUSION

This study investigates the evolving relationship between public interest and academic research concerning the shadow economy and renewable energy. The central aim was to assess how societal attention, measured through Google Trends, aligns with and potentially influences scholarly activity at the intersection of informal economies and sustainable energy transitions.

The findings reveal a notable and statistically significant relationship between public search interest in renewable energy and subsequent increases in academic publications on the topic. This suggests that public attention may act as a precursor or stimulus for scholarly engagement in this field. In contrast, search interest in the informal economy and feed-in tariffs demonstrated a weak or statistically insignificant influence on research output. The study also observed that academic interest in these interconnected topics has grown exponentially since 2000, with a marked acceleration after 2015, reflecting broader global movements around sustainability and green policy transitions. Country-level comparisons highlighted mismatches in some cases between public interest and academic productivity, underscoring disparities in research capacity or focus.

These findings point to several implications for policy. There is a clear need to better align academic research agendas with emerging public concerns, especially in contexts where societal interest outpaces scholarly attention. Encouraging interdisciplinary collaboration among energy policy, economics, and labor studies can provide deeper insight into the socio-economic dynamics of renewable energy adoption. Furthermore, improving public communication around technical energy policy concepts such as feed-in tariffs may enhance societal engagement and support for clean energy initiatives. The use of real-time public interest data, like that from Google Trends, also presents a valuable opportunity for policymakers and academic institutions to anticipate and respond to evolving societal priorities.

Ultimately, this study underscores the importance of a responsive academic landscape that not only contributes to policy development but is also informed by public discourse and demand. By examining the interplay between public interest and scholarly output, this study contributes to a more nuanced understanding of how knowledge production and societal engagement can mutually reinforce progress toward sustainable and inclusive economic systems.

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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" AND "energy") OR ("pure pumped storage" AND "energy") OR "marine energy" OR "wind energy" OR "solar energy" OR "bioenergy" OR "biofuel" OR "mixed power" OR ("bagasse" AND "energy") OR ("biogas" AND "energy") 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")))