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A bibliometric study on the nexus of economic growth and renewable energy in Brazil

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Abstract. The nexus between economic growth and the energy consumption is important in energy economics and economic development literature. The recent urgency in accelerating the decarbonization processes of economies has enhanced relevance to the analysis of this empirical relationship in the face of technological advances, regulatory changes, and the expanding uptake of renewable energy technologies worldwide. This article presents a bibliometric analysis of the literature on economic growth, energy consumption, and renewable energies in Brazil using clustering as a support tool. Between 1995 and 2022, 177 studies were published on Energy-Growth, Brazil, and Sustainability. It was found that China leads the ranking of publications, taking part in 28.84% of the production related to the link between economic growth and consumption of renewable energy in Brazil, followed by Turkey (21.52%) and Brazil (21.31%). The participation of other countries in the literature adds up to 32.29%. Keywords such as "ecological footprint," "environmental sustainability," "environmental Kuznets curve," and "emissions" show how in recent years, the literature has been guided by a discussion related to economic-environmental factors. Another result was that the Granger causality test is a research frontier with the most significant associated strength.

Keywords. economic growth, energy consumption, renewable energies, Brazil.

1. Introduction

The evolution of population well-being and projections of reduced poverty are intimately linked to economic growth; as a result, their determinants are critical to public administrators and private economic agents **[1,2]**. The study of the relationship between economic growth and energy consumption became vital because it is a fundamental part of the productive sectors and the consumption pattern of families.

Four are the primary hypotheses developed in research on the relationship between energy and growth **[3]**: (i) Increasing energy consumption fosters economic growth (hypothesis of growth), (ii) energy consumption does not directly affect economic growth (conservation hypothesis), (iii) Energy consumption is correlated with economic growth, which in turn increases energy consumption due to population growth's increased purchasing power (feedback hypothesis) and, finally, (iv) economic growth is neutral concerning changes in energy consumption (neutrality hypothesis).

In Brazil, renewable energy sources provide 83% of the country's internal electricity supply, with about 65% coming from hydroelectric sources **[4]**. Still, policies encouraging the adoption of renewable technologies have increased the contribution of other sources of energy in the nation, such as those solar and wind power.

This study aims to conduct a bibliometric analysis of the literature on the topic of economic growth and energy consumption under the umbrella of renewable energy sources for Brazil to guide researchers and public policymakers effectively. We divided this study into five sections in addition to this introduction. The critical elements related to the energy-growth-sustainability nexus will be presented in section 2. The clusterization and bibliometric methods are presented in Section 3. In section 4, the results are analyzed. Following that, the final considerations are conducted in Section 5.

2. Energy-Growth-Sustainability Nexus (EGS)

As previously mentioned, job and wage creation and second-plane consumption are one of the connections between energy and economic growth. According to International Energy Agency **[5]**, Between 1990 and 2018, the final electricity consumption related to the residential and industrial sectors increased by 138,5% and 107,2%, respectively. This movement will lead to the comparison of data on global electricity consumption: 10,879,90 TWh in 1990 and a 127,4% increase in 2018 **[6]**, making urban areas responsible for 64% of energy use and around 70% of carbon dioxide emissions worldwide, based on

projections from the International Energy Agency **[7]** and United Nations **[8]**.

According to the Renewable Energy and Jobs report from International Renewable Energy Agency, nearly 1,27 million new jobs were created in the renewable energy sector in Brazil in 2021. **[9]**, an increase of about 25% from the previous year. Approximately 67% of this total relates to the biofuel industry, making it the biggest employer in Brazil. Expansions in the wind energy sector led to record increases in the installed productive capacity of this source, reaching the accumulated mark of 21.2 GW. The agency estimates that around 63,800 workers are employed in the construction and operations & maintenance (O&M) of such projects and are located mainly in the country's northeast region, where the sector demands industries that manufacture equipment. The photovoltaic energy sector also grew in installed generation capacity by 5.5 GW in 2021, accumulating 14 GW in the country's energy matrix. Most of the installed capacity is located in the south and southeast. According to IRENA, one-third of the total photovoltaic energy installed in the country comes from distributed systems (up to 5MW).

Between 1996 and 2021, the average growth rate of the Brazilian economy was 0.55%, and since 1990, the country's overall demand for primary energy has doubled. According to a report from the International Energy Agency, this increase was caused mainly by the transportation sector's demand for electricity and fuel. **[10]**. Access to electric energy became almost ubiquitous thanks to private investments and primarily to government initiatives like the "Luz para Todos" program **[11,12]** and Social Electricity Tariff **[13]**.

Hydroelectric generation is responsible for 60% of the energy generated in the country **[13]**. It imposes uncertainties about the ability of energy demand to be met in the face of the resurgence of climate change. Despite this, hydroelectric generation is projected to increase by 36% by 2024 **[14]**. Studying the effects of investments in renewable energy on economic growth has become a crucial topic for Brazil, given the sector's enormous potential for growth.

3. Bibliometrics and clustering method

The bibliometric method is an interdisciplinary scientific approach to quantifying academic output from individuals and institutions concerning a specific topic. We will follow the approach taken by Hu *et al.* (2022) **[15]**, using CiteSpace and VOSviewer. VOSviewer and CiteSpace are bibliometric analysis software based on information visualization written in Java. From its results, it is possible to trace the development of the literature as well as trends and research frontiers **[17]**.

In the first step, we elaborated the keywords to extract the articles relevant to our study. The search criteria used consisted of the following: TITLE-ABS-KEY ((("energy consumption") AND ("economic growth") AND ("renewable energy") AND ("brazil")). We compiled the database for this study's sample using the Web of Science indexing basis. Using it, we are gathering studies related to influential periodicals that provide significant results for this field of research **[15]**. In the second stage, we quantitatively analyzed the collected sample as well as the proportion of types of publications included. In the third step, we used the VOSviewer software to analyze co-citation, co-authorship, regions/countries, and co-occurrence of keywords.

Then, we will perform the analysis of benchmarks and cluster analysis. Cluster analysis, or clustering, is a Multivariate Statistics procedure that aims to partition elements into two or more clusters considering their similarity according to pre-established criteria **[16]**. The dissimilarity between objects is measured by a distance matrix whose components resemble the distance between two points. Clustering methods can be described by a matrix of measures of dissimilarity or proximity between each pair of objects. Each p_{ij} entry in the matrix is a numerical value showing how close objects i and j are. The presented dissimilarity coefficients are functions **d: Γ X Γ ⇒ R**, where **Γ** is the set of things of interest. These functions allow the transformation of the data matrix,

$$\Gamma = \begin{bmatrix} x_{11} & \cdots & x_{1f} & \cdots & x_{1p} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{1l} & \cdots & x_{if} & \cdots & x_{ip} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{n1} & \cdots & x_{nf} & \cdots & x_{np} \end{bmatrix} \quad (1)$$

In a distance matrix,

$$\mathbf{d} = \begin{bmatrix} \mathbf{0} & & & & \\ \boldsymbol{d(2,1)} & \mathbf{0} & & & \\ \boldsymbol{d(3,1)} & \boldsymbol{d(3,2)} & \mathbf{0} & & \\ \vdots & \vdots & \vdots & & \\ \boldsymbol{d(n,1)} & \boldsymbol{d(n,2)} & \ldots & \ldots & \mathbf{0} \end{bmatrix} \quad (2)$$

being $\boldsymbol{d(i,j)}$ the calculated distance between the elements $\boldsymbol{i}$ and $\boldsymbol{j}$. The dissimilarity functions need to follow some criteria, namely:

$$\boldsymbol{d(i,j) \geq 0, \forall\, i,j \in \Gamma} \quad (3)$$

$$\boldsymbol{d(i,j) = d(j,i), \forall\, i,j \in \Gamma} \quad (4)$$

$$\boldsymbol{d(i,j) + d(i,k) \geq d(i,k), \forall\, i,j,k \in \Gamma} \quad (5)$$

After meeting the properties listed above, if the metric also has the property $\boldsymbol{d(ax,ay) = |a|d(x,y)}$, it is called the norm. For the construction of the clusters, we used the hierarchical method, which consists of identifying groups and the probable number $\boldsymbol{g}$ of groups by a series of successive mergers, or a series of consecutive divisions, having their results seen in the dendrogram, which illustrates the mergers or divisions made at successive levels.

VOSviewer calculates the score per author using the count and fractional method. The first equally scores the authors of a document, and the fractional criterion divides the score by the number of collaborating authors. And then, the force-association algorithm is used to normalize the raw data and build a distance and graph-based literature visualization map **[15]**.

4. Results

As a result, 177 documents were collected, and their types are distributed as shown in Figure 2. 79% of the sample is

made up of peer-reviewed articles, which is helpful for the implications of our analysis of the results.

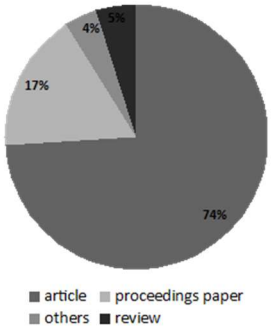

Fig. 1. Publication types - keywords “energy consumption” AND “economic growth” AND “renewable energy” AND “brazil.” Source: Prepared by the authors

The documents cover the period from 1995 until 2022 and the annual literature growth is 13.83%, to which 520 authors are linked. Figure 2 illustrates the number of publications per year.

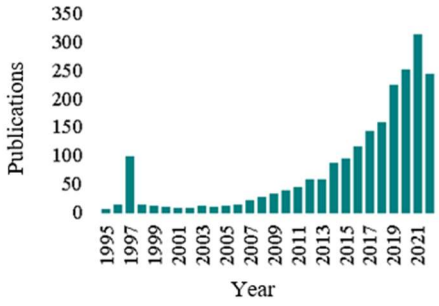

Fig.2. Number of publications per year - keywords “energy consumption” AND “economic growth” AND “renewable energy” AND “brazil.”. Source: Prepared by the authors.

Figure 3 shows the visual map of cooperation between countries/regions with a temporal layer. The node’s size indicates the number of documents, and the colour indicates each country's average year of publication separately. The thicker the line connecting two nodes, the greater the degree of cooperation between countries.

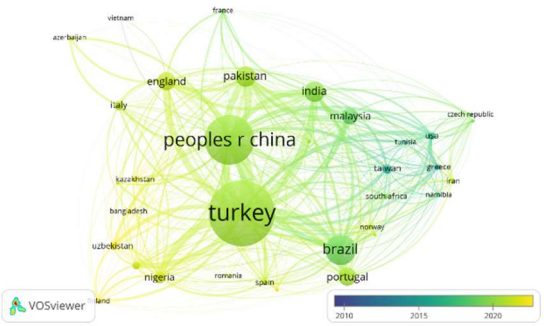

Fig. 3. Cooperation networks between countries/regions in nexus EGS. Source: Prepared by the authors based on data collected on the Web of Science.

As seen in Figure 3, it is not surprising that China is at the top of the list of studies related to renewable energy, given that it is also at the top of the list of investments in RD&D for renewable energy in 2021 **[18]**. This has the effect of encouraging countries in the Asia-Pacific region to pursue similar energy transition goals, diversifying their energy portfolios, and providing energy security to nations with high levels of hydrocarbon reserve depletion. Countries like Uzbekistan, Mozambique, Bangladesh, and Nigeria have contemporary literature in this field of study and strongly resemble Turkey and China, albeit with less quantitative evidence. Table I summarizes the results for the Top 10 most relevant countries/regions in EGS nexus literature.

Table I. – Top 10 most relevant countries/regions in EGS nexus literature

Rank	Country/region	Documents	TC	AAC
1	China	143	1627	40,67
2	Turkey	124	1212	39,10
3	Brazil	123	559	15,53
4	India	37	190	21,11
5	Portugal	59	175	17,50
6	Malaysia	21	168	28,00
7	Tunisia	3	121	121,00
8	United Kingdom	20	121	40,33
9	Pakistan	37	88	12,57
10	Spain	9	80	26,67

Source: Prepared by the authors based on data collected on the Web of Science.

The ten most essential affiliations in the literature on Brazilian economic growth and renewable energy consumption are listed in Table II, ranked by the number of articles published. This list is led by the International University of Cyprus (11 articles), the University of Gelisim in Istanbul (6 articles), and the University of Sakarya (5 articles). It's important to note that even though fewer articles have been published by organizations like King Abdullah University of Science and Technology, Huaqiao University, and National Chiao Tung University, these organizations have more citations overall than the organizations that topped the ranking.

Table II. – Top 10 most relevant affiliations in ESC nexus literature

Rank	Institution	Country/region	Documents	CT
1	International University of Cyprus	Cyprus	11	178
2	Istanbul Gelisim University	Turkey	6	93
3	Sakarya University	Turkey	5	162
4	Coimbra University	Portugal	4	46
5	COMSATS University Islamabad	Pakistan	3	165
6	Eastern Mediterranean University	Cyprus	3	116
7	European University of Lefke	Cyprus	3	90
8	University of Beira Interior	Portugal	3	75
9	South Ural State University	Russian	3	72
10	Évora University	Portugal	3	2
11	Bournemouth University	England	3	36
12	King Abdullah Univ. of Science and Technology	Saudi Arabia	2	386
13	Huaqiao University	China	2	243
14	National Chiao Tung University	Taiwan	2	243
15	Goa Institute of Management	India	2	168

Source: Prepared by the authors based on data collected on the Web of Science.

We used VOSviewer to visualize cooperation networks in the EGS Nexus literature (Figure 4). The node size stands for the number of documents per institution. The width of connections indicates the degree of cooperation between organizations. The wider the link, the greater the existing collaboration between institutions. The set of nodes of the same colour is a cluster, organizations with a substantial degree of cooperation. We can see from Figure 4 that there are six institutional groupings, and those in green and red have the most significant number of connections. The red cluster has Sakarya University with greater centrality in

relationships and has extensive collaboration with several institutions, with no one standing out due to recurrence. On the other hand, the University of Coimbra cooper strongly with Evora University, Beira Interior University, and Fluminense Federal University.

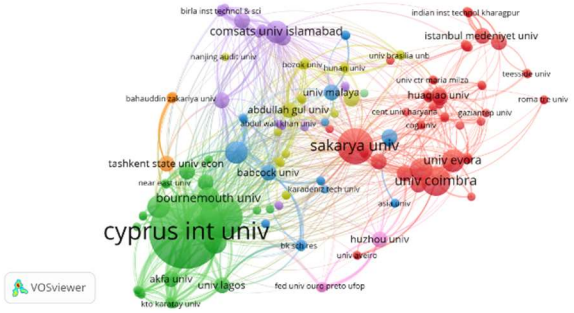

Fig.4. Institutional research cooperation networks in the literature nexus. in nexus EGS. Source: Prepared by the authors based on data collected on the Web of Science.

Other institutions are grouped, as we can see in Figure 4, forming a broad network of cooperation and collaboration in research. These studies relate to topics such as the environmental Kuznets curve, CO2 emissions, and empirical analyzes of energy consumption and economic growth in E7 countries.

Figure 5 shows research collaboration networks, including authors with at least one article. Collaboration in this field shows a large set of clusters. However, few groups are linked. It is worth paying attention to the restriction of the research field we carried out, which may reduce the possibility of overlapping themes. In addition, some research areas suffer from the phenomenon known as the small world effect, in which collaborations are restricted to people in the immediate circle of the authors, making it challenging to share methods, resources, and knowledge **[19]**.

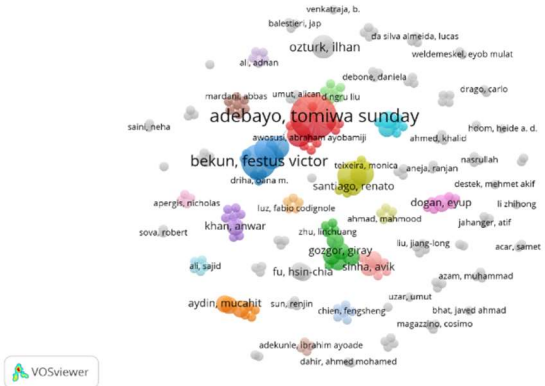

Fig.5. Cooperation networks between different authors. Source: Prepared by the authors based on data collected on the Web of Science.

An author's productivity is an essential indicator of their influence on literature. Table III lists the ten most productive authors for literature. The list is led by author Tomiwa Adebayo, followed by Andrew Alola and Murad Bein. These authors are linked to the International University of Cyprus, located on the Island of Cyprus. Cyprus is currently developing essential projects in the energy sector alongside Europe. It has attracted researchers and entrepreneurs from the industry to the region, a process that became more intense after discovering hydrocarbon sources on the coast of the Island.

Table III. – Top-10 most relevant authors in the EGS literature nexus.

Rank	Author	País	Documents	CT	h-index
1	Adebayo, Tomiwa Sunday	Cyprus	7	113	5
2	Alola, Andrew Adelale	Cyprus	3	14	2
3	Bein, Murad	Cyprus	3	61	2
4	Bekun, Festus Victor	Cyprus	5	183	4
5	Cunha, João	Portugal	3	80	3
6	Fuinhas, José Alberto	Portugal	6	122	5
7	Koengkan, Matheus	Portugal	4	68	3
8	Nunes, Manuel	Portugal	4	80	3
9	Ferraz, Diogo	Brazil	4	99	2
10	Sinha, Avik	India	2	163	2

Source: Prepared by the authors based on data collected on the Web of Science

The journal co-citation analysis allows observing the major journals in the research field. When at least one article from two journals occurs concurrently in a cited paper, both journals will have a citing relationship in common. Figure 6 shows the visualization of journal co-citation networks. The node size represents the number of common citations: the more significant this number, the greater the importance of the journal for the topic.

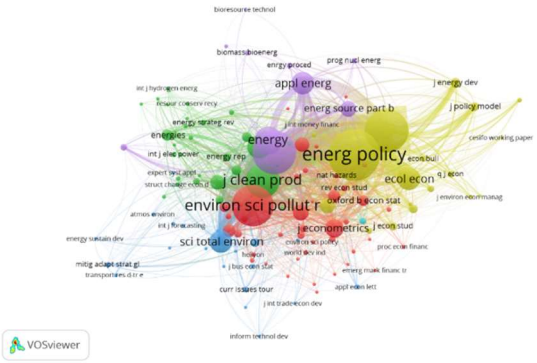

Fig.6. Visualization of journal co-citation analysis. Source: Prepared by the authors based on data collected on the Web of Science.

The analysis of authors' co-citations aims to identify authors with a high citation rate, configuring it as an essential element to identify multidisciplinary trending and related research areas. The view of co-citation relationships is shown in Figure 7. Nodes indicate authors, and connections represent co-citation relationships. As in previous analyses, the size of the nodes means the citation number for the author that labels the node – i.e., the more prominent, the more influential the author.

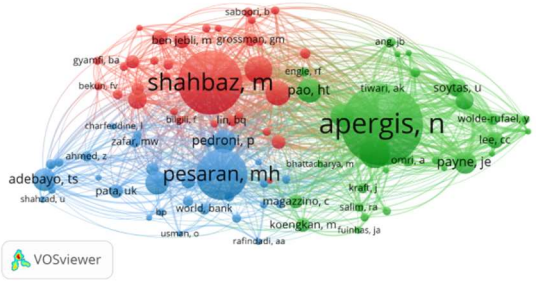

Fig. 7. Author co-citation analysis visualization map. Source: Prepared by the authors based on data collected on the Web of Science.

Keywords are words extracted from the text (title, abstract, or body of the document) that seek to synthesize the main content of the research in terms of hypotheses, methods, and/or evidence. Thus, analyzing the co-occurrence of specific keywords among the documents of a research field can indicate a possible theoretical and empirical approach predominant in the literature, as well as likely trends and frontiers to be developed. In Figure 8, we present the co-occurrence of keywords grouped by clusters. We see five main groupings, with very defined themes interconnected by nodes that refer to economic methods.

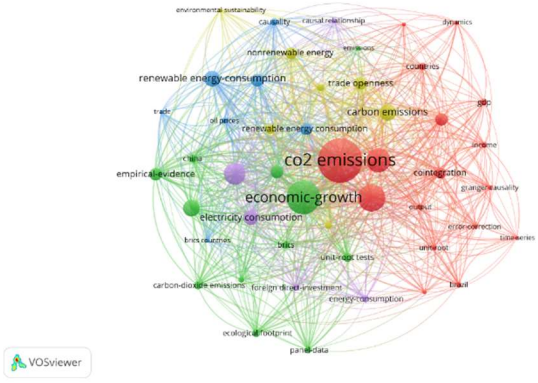

Fig.8. Atlas of visualization of the co-occurrence analysis of keywords by clusters. Source: Prepared by the authors based on data collected on the Web of Science.

CiteSpace's burst detection can assess the most referenced keywords and their importance. Table IV presents the four keywords that had an explosive process between 2006 and 2022. The table shows the relevant period of each keyword and the measure of the intensity related to its use in the explosive interval in the strength column. The greater the value of the force, the greater the occurrence and co-occurrence of the word in the period.

Table IV. - Top 15 keywords ranked by citation burst

Rank	Keywords	Year	Strength	Start	End
1	Granger causality	2006	3.33	2013	2017
2	Fresh evidence	2006	2.64	2019	2020
3	Error correction	2006	2.32	2013	2015
4	Foreign direct investment	2006	2.29	2016	2018
5	Non-renewable energy	2006	2.23	2018	2018
6	Oil price	2006	2.16	2020	2020
7	European union	2006	2.09	2018	2018
8	Brazil	2006	2.09	2016	2016
9	Efficiency	2006	2.09	2016	2016
10	Panel cointegration	2006	2.09	2016	2016
11	Time series	2006	2.08	2013	2013
12	Causal relantionship	2006	2.04	2019	2020
13	Unit root	2006	2.03	2013	2015
14	Test	2006	2.03	2013	2015
15	Unit root test	2006	1.90	2016	2017

Source: Prepared by the authors based on data collected on the Web of Science.

Explaining explosions related to keywords stands for a research frontier by identifying the rise and fall of a given field of knowledge. Table IV shows that Granger causality is a research frontier with the highest associated strength. The causal investigation through the Granger test appears in the seminal article by C. W. J. Granger in 1969, reporting the difficulty of analysts in deciding the direction of causality in two related variables and evaluating whether a feedback process is taking place **[20]**. After Granger's proposal, methods for dealing with autoregressive vector models have been improved over time with Toda & Yamamoto **[21]**, Jones & Wenders **[22]**, and Nazlioglu *et al.* **[23]**.

The challenge of establishing a causal relationship between variables is renewed whenever a new method is available in the literature. This explains part of the strength of the fresh keyword evidence in this literature, occupying second place in the list. Meta-analyses were developed with the objective of, through the compilation and statistical synthesis of individual estimates, statistically stating whether the causality between renewable energy consumption and economic growth occurs unidirectionally or bidirectionally. Ozturk (2010) **[24]** concludes in the survey he carried out on the nexus between energy and change that there is no consensus on the existence or direction of causality between electricity consumption and economic growth. For the specific case of renewable energy consumption, a similar result is found by Sebri (2015) **[3]**. The author compiled 40 empirical studies, generated a base of 153 observations, and performed a meta-regression with moderating variables taken from the studies. Part of the heterogeneity found in the estimates in the literature is due to the types of data and the grouping method used.

The empirical analysis of the causality between economic growth and energy consumption is one of the most common analyses carried out by researchers. It is mainly used to determine the implications of energy policies or to evaluate structural changes in the energy matrix of regions. Applying it to the case of renewable energies, several articles have analyzed the impacts of renewable and non-renewable energies on the economic growth of selected countries and their effect on total carbon dioxide (CO2) emissions. The commonly used method for this is the causal asymmetry test, developed by Hatemi-J (2012) **[25]** which seeks to investigate downward and upward relationships, admitting the existence of different behaviours between these variables depending on the accumulation of positive or negative shocks.

Still, the issue of renewable energy consumption is also related to the well-being resulting from improvements in the environmental quality of countries. Thus, the second topic, grouped under the keyword "environmental quality," seeks to measure the impact of energy consumption on economic growth and CO2 emissions. One author who stands out in this hotspot is T. S. Adebayo. In recent years, research has been carried out on the impact of CO2 emissions on the economic performance of countries. Such as South Korea, Japan, South Africa,

Malaysia, and others The most used methods consist of the ARDL bounds test and wavelet coherence techniques.

5. Final considerations

This study's goal was to perform a bibliometric analysis of Brazil's economic growth and renewable energy sources. Complete document data from the Web of Science database were used. Data description and visualization were obtained using the programs CiteSpace and VosViewer. Between 1995 and 2022, 177 studies were published on Energy-Growth, Brazil, and Sustainability. It was found that China leads the ranking of publications, taking part in 28.84% of the production related to the link between economic growth and consumption of renewable energy in Brazil, followed by Turkey (21.52%) and Brazil (21.31%). The participation of other countries in the literature adds up to 32.29%. Keywords such as "ecological footprint," "environmental sustainability," "environmental Kuznets curve," and "emissions" show how in recent years, the literature has been guided by a discussion related to economic-environmental factors. Another result was that the Granger causality test is a research frontier with the most significant associated strength.

An extensive and comprehensive co-authorship and co-citation analysis are performed, and hot research and research frontiers are discussed. The crucial role of topics related to the financial sector, the application of new econometric methods of causal identification on unconsolidated empirical evidence, and the importance of technological innovations for the frontier of research on this topic are highlighted.

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