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Connections between Energy Consumption, Economic Growth, and Pollution: A Bibliometric Analysis from the Perspective of Climate Action and Public Awareness

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Abstract. *The aim of this paper is to perform a bibliometric analysis to identify the main scientific contributions on the interrelations and causal relationships between conventional energy consumption, renewable energy consumption, and the level of economic growth and pollution in an interdisciplinary manner for policy impact analysis. The analysis included 971 scientific publications that were indexed in the Web of Science Core Collection and was conducted on 9 August 2024. Using the VOSviewer software tool and bibliographic elements, the main results demonstrate that, in recent years (e.g. 2018-2024), there has been a growing focus among authors on identifying tangible solutions through the formation of research teams and academic collaborations in the fight against pollution. The transition to the use and consumption of renewable energy resources is becoming a pragmatic and beneficial action in the promotion of a clean, sustainable, and carbon-free environment, with a positive and increasing impact on public administration, urban planning, and education in both the public and private sectors. Furthermore, our results demonstrate that these energy-economy-environment interactions are addressed from an interdisciplinary perspective, with many academic publications focusing on specific issues related to public taxation, greening, municipal solid waste, responsible consumption and production, urban planning, and public management.*

Keywords: bibliometric analysis, causality analysis, renewable energy sources, public administration, carbon neutrality, ecological footprint, sustainable environment.

Introduction

The complexity of the energy system at national, regional, or global level is given by the main links and causal relationships with economic growth, economic development, and environmental sustainability. It is also a highly debated and discussed topic in the scientific community.

Recently, there has been a growing interest on the part of researchers and academics to explore and study the main causal relationships between the energy system, economic growth, and the promotion of a clean and sustainable environment, by finding empirical evidence at national, regional, community and international/global levels (Apergis and Payne, 2010; Abumunshar et al., 2020; Balsalobre-Lorente et al., 2018). Following this direction, the main objective of our study is to carry out a systematic and detailed review ofacademic literature

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dealing with the interdependencies and linkages between the consumption of traditional energy resources (e.g. fossil fuels), the consumption of renewable energy resources, economic growth, and pollution (measured in terms of carbon dioxide emissions).

The motivation of this study is to illustrate and identify the most representative academic publications in this field of research, highlighting those scientific contributions that, in an interdisciplinary way, capture the complexity of the energy system and how energy consumption has an increasing impact on economic growth and, implicitly, on the natural environment (Destek, 2016; Chu, 2012; Fadiran et al., 2019). In this respect, the main research questions (RQ) that underpin the scientific approach of this article are as follows:

RQ1: "How many publications deal with this topic, and which are the most relevant?"

RQ2: "What are the main practical and empirical issues found in these publications?"

RQ3: "Can clusters be identified in terms of the most important keywords and scientific information found in these academic publications?"

RQ4:" What are the main future directions to be pursued by identifying these keywords and connections/relationships between them?"

To answer these questions, from a methodological point of view, we will use the quantitative research method of bibliometric analysis (Lim and Kumar, 2024; Stratone, 2023) by means of the VOSviewer software. The database is constituted by the number of publications indexed and included in the Web of Science Core Collection on the following four search terms: "energy resources", "economic growth", "renewable consumption" and "CO_2 emissions". Specifically, we will be able to discuss and analyse these resulting publications according to several elements, namely: year of publication, number of citations, profile of authors, countries of origin, academic journals of publication, scientific publishers, categorization of publications, analysed topics, as well as the occurrence and links between the keywords which form these clusters.

Moreover, considering climate change and the increasing pressure of economic activities and sectors (in our case, the dynamics and evolution of the energy system), this study provides a detailed and rigorous review of the literature, which represents a guide for future concerns of researchers and scientists on all that is climate action. Our study therefore contributes to raising awareness and educating the public on the virtues of environmental protection and the transition to renewable energy, which are currently the solutions and levers aimed at economic sustainability.

The present study is organized in several sections: Section 2 introduces the literature on the energy consumption-economic growth-pollution nexus. Section 3 presents the database, sources of information, research method and applied research tools. Section 4 presents and discusses the results obtained by applying bibliometric analysis, while the conclusions and future directions of the study are included in Section 5.

Literature review

This section is divided into several parts in order to provide a better overview of the existing literature dealing with the interdependencies between energy consumption, the use of renewable energy sources, economic growth and the environmental component suggested by the amount of carbon dioxide emissions.

Energy consumption and economic growth

Natural gas and oil are the main drivers of a country's economy. Therefore, it is desirable to explore the positive impacts and externalities that these energy resources have on economic activity. From this perspective, there are an increasing number of empirical studies that examine the different types of causal and cointegration relationships between energy consumption, economic growth, and pollution at the national, regional, and global levels.

Narayan and Smyth (2007) are among the first researchers to examine the long-term interdependences between oil consumption and economic activity (the growth rate of GDP) in a panel analysis for the countries of the Middle East. The analysis covered the period 1971-2002, and the main findings showed the significantly increased impact of oil consumption on economic growth in the region, as well as the fact that oil demand in the Middle East is largely driven by strong economic growth, while consumers are largely insensitive to price changes.

We also mention the study conducted by Narayan and Wong (2009), whose main motivation was to conduct a panel data analysis model to examine the relationship between oil consumption and its determinants, namely oil prices and income, in the six Australian states between 1985 and 2006. The results suggest that GDP has a statistically significant and highly direct impact on oil consumption, which contributes to increasing inflationary pressures and destabilizing the financial-monetary system in the future. This trend is accompanied by a strong interest in studying the impact of natural gas on economic activities (Villada and Olaya, 2013; Kum et al., 2012; Apergis and Payne, 2010). The study conducted by Farhani et al. (2014) aims to assess the direct impact of natural gas consumption on economic growth in Tunisia from 1980 to 2010. The main findings point to a long-term causal relationship between natural gas consumption, gross capital accumulation and the balance of trade at the level of GDP.

The study by Fadiran et al. (2019) examines the long-term causal relationship between natural gas consumption and economic growth in 12 European countries over the period 1991-2016. The explanatory variables used included gross fixed capital formation, labour force, trade openness and real GDP, while the main econometric techniques used were panel cointegration regressions (FMOLS and DOLS approach), vector error correction model and Dumitrescu-Hurlin panel Granger causality test. The main findings concerned the existence of a statistical and negative relationship between natural gas consumption and economic growth in most European countries, as well as the existence of a one-way relationship between natural gas consumption and gross fixed capital formation (gross investment).

The results also suggest the existence of the growth hypothesis in Austria, Bulgaria, and Switzerland, while the United Kingdom (UK) and Italy support the conservation hypothesis. Similarly, the results of Apergis and Payne (2010), Destek (2016), Balitskiy et al. (2016) validated the main Granger causality relationships to confirm the growth, conservation, neutrality and feedback hypotheses between natural gas consumption and economic growth in European and OECD countries.

Xiong and Wu (2008) showed that the GDP level, the population, the total oil price, and the share of the industrial sector in GDP are the statistically relevant factors affecting the long-term annual natural gas consumption in China. Moreover, the forecasting analysis conducted by using the cointegration model and the vector error correction model suggested that natural gas demand will show an increasing trend during 2008-2020, which means that China will face more and more serious energy problems, for which some suggestions are proposed to policy makers.

The central objective of the study conducted by Liang et al. (2019) is to provide an outlook/forecast analysis of China's natural gas consumption for the period 2008-2018. The

authors integrated many explanatory variables to describe economic activity, natural gas production, overall natural gas prices, alternative energy prices and energy policy issues. The results obtained by applying the Markov Switching Model, the Product Partition Model and the Bayesian Model Average indicated two short-term phases of natural gas consumption growth, i.e. rapid growth, and slow growth, with different degrees of intensity and diffusion (these growth rates are between 0.9% and 1.22%). At the same time, these forecasting models have identified the seasonal effects on natural gas consumption, and the possible ultra-rapid growth of consumption in the future represents a new demand for natural gas supply.A similar approach is found in the study by Balsalobre-Lorente et al. (2019). These authors conclude that natural gas consumption plays an important role and has a positive impact on economic growth, confirming the growth hypothesis often discussed and debated in the literature.

The study conducted by Aimer and Hamoudi (2018) showed the existence of a bidirectional causal relationship between economic growth (GDP growth) and oil consumption for the eight net oil exporting countries during the period 1997-2013. Methodologically, panel cointegration models and vector error correction models were applied in this empirical study. Other empirical evidence on the estimation of natural gas consumption was noted by Tatli (2018). Applying the panel analysis to the 18 selected OECD countries over the period 2004-2015, the results suggest that natural gas consumption/demand is negatively affected by price developments, with an inelastic elasticity in the long run.

A novel contribution to the forecasting of crude oil consumption is proposed in the study by Yu et al. (2019). The authors built an innovative econometric model (an online big data driven forecasting model for oil consumption), which made it possible to estimate and forecast monthly natural gas consumption based on online big data (in this case, Google Trends was used) in the interval 2004-2015. The results of the study showed that the introduction of online data ("oil consumption" and "oil price" Google Trends) is helpful in improving the accuracy of the level prediction for global oil consumption, which is validated by the low values of the performance indicators in the prediction analysis - MAPE, RMSE and the positive value of the Improvement Rate (IR). Nevertheless, after applying the causality analysis, a unidirectional Granger relationship was observed between Google Trend and global oil consumption.

Energy use, economic growth, and environmental impact

Net energy importing countries are increasingly turning to natural gas as an alternative energy source to meet their environmental objectives of reducing carbon dioxide emissions.

In line with the study conducted by Farhani et al. (2014), other studies (Ighodaro, 2010; Khan and Ahmed, 2008; Hu and Lin, 2008; Işik, 2010) have found unidirectional and bidirectional causal relationships between natural gas consumption and economic growth, with faster adjustment of natural gas consumption than GDP and long-run equilibrium. They used various econometric methods and techniques, including panel analysis (common effects, fixed effects, and random effects models), cointegration methods (FMOLS and DOLS regressions), Granger and Dumitrescu-Hurlin causality tests and autoregressive models (VAR, VEC and ARLD models).

Most of the empirical studies (Brabec et al., 2008; Erdogdu, 2010; Farhani et al., 2014; Işik, 2010; Kum et al., 2012; Kaplan et al., 2011; Grigore, 2023) have focused on determining and assessing the causal relationships between consumption and production of domestic energy resources and economic growth and economic development. In this regard, the authors present several hypotheses: the growth hypothesis (showing a one-way causality from energy

consumption to economic expansion), the conservation hypothesis (showing a one-way causality from economic progress to energy consumption), the feedback hypothesis (establishing the causal relationship between energy consumption and income), and the neutrality hypothesis (showing no causality between income and energy consumption).

In this regard, we include the study conducted by Chu (2012), which statistically tests these causal relationships at the level of 49 states over the period 1970-2010. The proposed methodology was panel analysis (i.e., bootstrap panel causality analysis), and the variables used were total crude oil consumption and real GDP per capita with an annual frequency. At the same time, the presence of cross-sectional dependence and heterogeneity across countries was tested, providing consistent and specific results depending on the geographical cluster of countries (16 European countries, 6 transition countries, 5 Middle Eastern countries, 9 Latin American countries and 13 Asian countries). The specific results showed that the nature of the causality between oil consumption and economic growth supports the growth hypothesis for 5 countries, the conservation hypothesis for 13 countries, the feedback hypothesis for 7 countries and the neutrality hypothesis for the remaining 24 countries studied.

Furthermore, climate and population are the most important factors influencing the evolution of natural gas demand in the residential sector.We have mentioned the notable works of Soldo (2012), Tamba et al. (2018) and Šebalj et al. (2019). Understanding the importance of these energy sources is crucial in the context of research activities. The main objective of these studies was to conduct a thorough and comprehensive review and synthesis of the scientific literature in this field. To achieve this, the authors have sequentially outlined various studies, categorized according to their application, data, tools, and models used to investigate and forecast the causal relationship between natural gas consumption and economic activity in the countries under study.

The paper is a valuable source of background information for future research in energy and economic development, with particular emphasis on forecasting tools and econometric techniques such as statistical, econometric, mathematical, dynamical systems and simulated annealing models. The author also emphasizes the need for theoretical advances in the field and recommends that future researchers use a variety of techniques, models, and data to forecast natural gas supply, demand, production, and prices.

The similar results on the prediction of natural gas consumption could be observed by applying multivariate regression models with panel data (Gorucu, 2004a; Gorucu 2004b; Liu et al., 2021), ARIMA-GARCH autoregressive models (Erdogdu, 2010) or combined prediction models - artificial neural network, grey or hybrid models (Boran, 2015; Park and Hong, 2013; Akouemo and Povinelli, 2016; Akinsola et al., 2020).Manowska et al. (2021) propose a hybrid model to forecast annual natural gas consumption for Poland in order to improve energy efficiency and security at the national level in line with the EU's main energy policy objective (the pursuit of EU climate neutrality by 2050).

Based on econometric forecasting models (ARIMA model and LTSM artificial neural network architecture), the first conclusion is that the European energy market is integrated, and that long-term equilibrium can be achieved by increasing the use of renewable energy sources as a protection mechanism against the fluctuating price movements of fossil fuels, in particular coal, oil, and natural gas. Secondly, the high performance of the models used (the average percentage error is 2%, which translates into a good forecast) and the fact that the level of natural gas consumption in Poland will have an increasing trend until 2040. We can strongly affirm that this

European country (i.e. Poland) will constantly, consistently, and intensively continue to improve its energy priorities by using natural gas as the main substitute for traditional energy resources.

Growing awareness of the negative impacts of climate change on economies has led to international cooperation to reduce greenhouse gas (GHG) emissions in European countries. This led to the establishment of national targets under the Kyoto Protocol in 1997 and continued efforts in this direction, culminating in the Paris Agreement of 2015 (Izanloo et al., 2021; Kum et al., 2012; Østergaard et al., 2020; Ozturk and Al-Mulali, 2015; Park and Hong, 2013; Pirlogea and Cicea, 2012). At the same time, government authorities show a strong inclination towards energy conservation to create a nature-friendly ecosystem, as shown by empirical research (Jahangir and Dural, 2018; Balitskiy et al., 2016; Bilgili et al., 2016; Huang et al., 2015; Iskin et al., 2012). In this direction, there are empirical studies that investigate the long-term causal relationship between natural gas consumption, oil consumption, oil and gas production and CO_2 emissions.

The study conducted by Dong et al. (2017) comes to our attention, as their results show that natural gas consumption has a statistically significant negative impact on the level of carbon emissions in the 30 provinces in China from 1995 to 2014.Methodologically, they used fully modified ordinary least squares (FMOLS) and dynamic panel OLS (DOLS), and the main results show that in the long run there is an inverted U-shaped environmental Kuznets curve relationship between per capita CO_2 emissions and per capita gross domestic product (GDP). Moreover, the policy implications of this study revolve around the formulation of new and effective environmental laws and regulations by the local government will play a crucial role in protecting the environment and contributing to GDP at the provincial level.

At the same time, the focus should be on reviewing the energy structure to achieve a win-win combination of reduced CO_2 emissions and economic growth in China. An inverted U-shaped relationship between CO_2 emissions and GDP in both the short and long term, which supports the EKC hypothesis, is also confirmed in other studies. In the same direction, we mention studies by Sentürk and Sataf (2015); Kalyoncu et al. (2013); Kaplan et al. (2011), which show that GDP, energy consumption and CO_2 emissions are cointegrated in the long run, in most cases also accepting the feedback and growth hypothesis.

Using the environmental Kuznets curve model in Türkiye, Abunmunshar et al. (2020) identified the positive impact of the use of energy resources (especially coal, oil, natural gas) on the annual consumption of carbon dioxide emissions, as well as the various effects of the global price of oil and the use of renewable resources on CO_2 emissions.

In addition, the results of the co-integration analysis suggested that oil prices have a negative impact on CO_2 emissions in Turkey in the long run, and these empirical findings can be attributed to the fact that Turkey is highly dependent on imported oil, with more than 50% of its energy needs being met by imports. The Environmental Kuznets Curve (EKC) hypothesis holds in this country, and the authors point to the positive impact of increased use of renewable resources on the achievement of future sustainable environmental policy goals. As such, these findings are important for oil importing and exporting countries in terms of diversifying their energy mix towards more renewable alternatives.

Methodology

The main objective of this study is to perform a bibliometric analysis of the association and interrelationship between conventional energy sources (natural gas, oil, fossil fuels), renewable energy consumption, economic growth and pollution measured by carbon dioxide emissions. In

this respect, we consider it important and useful to capture these interdependencies between the energy economy and the environment through a detailed and rigorous analysis of the scientific literature specific to this field, with an increasing and accentuated impact for researchers, academics, but also practitioners in the energy field.

Bibliometric analysis is considered to be an essential quantitative research method in the scientific field, based on a number of pillars and central factors, such as the description, identification, systematization, synthesis, explanation of scientific literature in a given field and area/sphere of research, as well as the deepening and opening new directions of research increasingly innovative and higher quality (Lim and Kumar, 2024; Donthu et al., 2021; Sweileh, 2020; Merediz-Solà and Bariviera, 2019). To fulfil the objective proposed in our study, the first step was to search for the following keywords: "energy resources", "renewable consumption", "economic growth", "CO_2 emissions", to create the base of scientific and academic articles relevant to our topic.

This search was conducted within the Web of Science Core Collection, one of the most relevant and popular research platforms owned by Clarivate Analytics, which consistently contributes to the quality of research in academia. The Web of Science is one of the world's most important sources of scientific documentation. The purpose of this database is to provide information on the scientific recognition of scientific articles and to identify new trends and technologies worldwide. It also provides access to article abstracts from over 12,200 scientific journals and 160,000 scientific conferences in 256 disciplines and more than 30,000 books. Practical benefits include easy, flexible, user-friendly access and the fact that full-text online scientific articles are identical to those in print (Einformation, 2022).

At the same time, searches can be carried out by keyword, author, journal title, article title or advanced searches using a series of filters introduced by the researchers, allowing the information to be analysed and different trends and patterns in research to be identified. For example, the results generated by the keyword search have drawn our attention to the fact that there is an increasing and significant pace in the links that can be established between the consumption of energy resources, economic growth, and the level of carbon dioxide emissions. Specifically, for the four search terms "energy resources", "economic growth", "renewable consumption" and "CO_2 emissions", a total of 971 publications were found. In this sense, the bibliometric analysis is carried out considering the 971 publications generated by the Web of Science Core Collection platform on 9 August 2024.

Each of the 971 publications contains relevant information on the subject, citation information, bibliographic information, abstract, keywords, funding details, and other information. From a methodological point of view, the conduct of this bibliometric analysis involves the systematic examination of the generated publications according to the following aspects: type of publication, academic journal, year of publication, profile of researchers and academics, research fields, citation topic macro, citation topic micro, geographical region, publisher, number of citations and other relevant aspects (here, we mention the Sustainable Development Goals and the tree map by Web of Science category).

The bibliometric software VOSviewer was then used to process the systematic literature review and then to both analyse and visualize the co-occurrence of keywords by generating a map embedded in the bibliographic data already mentioned. VOSviewer is a software tool for the construction and visualization of bibliometric networks. These networks can include, for example, journals, researchers, or individual publications, and can be constructed based on citation, bibliographic coupling, co-citation, or co-authorship relationships. VOSviewer also

provides text mining functionality that can be used to construct and visualize co-occurrence networks of important terms extracted from a body of scientific literature.

The perspectives derived from the bibliometric analysis will contribute to the achievement of the objectives of the paper and to the understanding of the term association and its possible implications in business practice. Bibliometric analysis allows for a comprehensive understanding of a research topic, including defining its boundaries, identifying key authors, and developing new research directions (Donthu et al., 2021; Merediz-Solá and Bariviera, 2019). The specific methodological approach that has been followed in this research paper is illustrated in Figure 1.

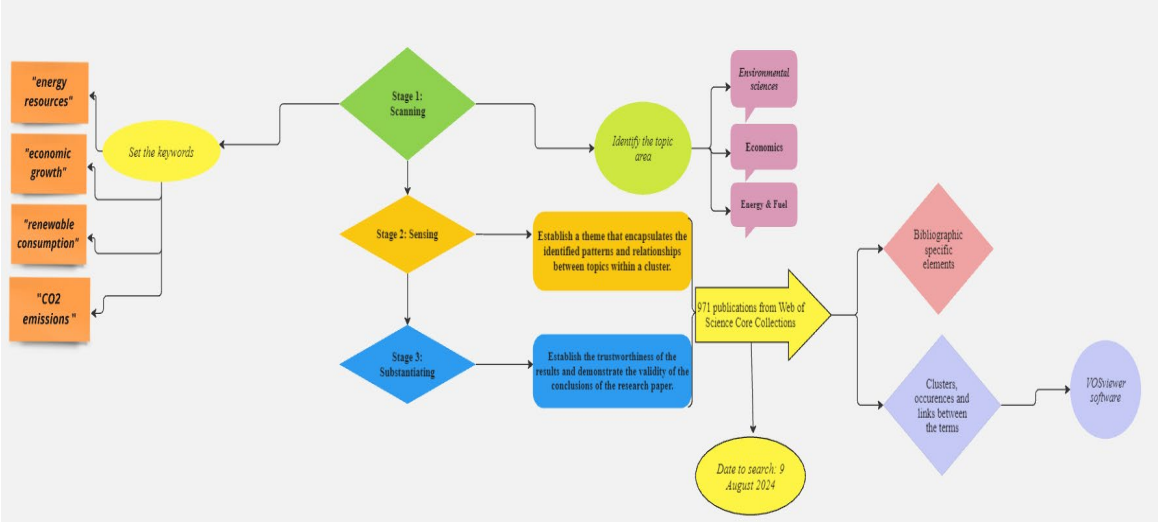

Figure 1. Methodological procedure according to the systematic bibliometric analysis

Source: Authors 'own contribution.

Considering that this article explores the links between energy resources, economic growth and pollution reduction from a multidisciplinary perspective, through the application of bibliometric analysis, an important step is proposed to identify, filter, select and justify the selection criteria of the studies dealing with this topic in the existing literature. From a methodological point of view, we believe that the inclusion of these selection criteria in the specific analysis of the 971 scientific articles will lead to a better match between the research objective and the research questions proposed at the beginning of this study, as well as to a concrete way of interpreting the results obtained and drawing viable recommendations and proposals on the impact of renewable energy resources on the economic path and on pollution reduction.

According to the findings of the study by Öztürk et al. (2024), the success of a bibliometric analysis lies in a good balance between the overall aim of the study, the methods and techniques used to collect relevant data from the literature, and the interpretation of the results to generate new directions for research. However, any bibliometric analysis must be able to provide practical implications for the field, area or topic, where clear, concrete steps in a logical sequence are required. Furthermore, these authors have shown that, after the search and identification of keywords, authors must go through a filtering stage to determine and apply the inclusion or exclusion criteria (Passas, 2024).

In light of these aspects, the selection criteria that we used to compile/acquire the 971 scientific articles were determined by a number of methodological, practical and empirical factors

that strengthen the transparency of the research. Table 1 presents and justifies these selection criteria.

Table 1. Specific selection criteria for our bibliometric analysis performed

No.	Criteria	Justification
1.	Type of documents	All types of documents that are included in Web of Science database (i.e. Article, Review Article, Proceeding Paper, Book Chapter, Book Review, etc.).
2.	Publication years	From 1994 up until 9 August 2024.
3.	Languages	All languages (The majority of the articles are written in the English language).
4.	Research fields	Economics, Business, Management, Public Administration, Environmental Sciences, Political Sciences, Business Finance, etc.
5.	Publication Titles	All the journals that are indexed in Web of Science Core Collection.
6.	Indexes	All indexes that are included in the Web of Science database (i.e. ocial Science Citation Index (SSCI), Science Citation Index Expanded (SCI-E), Emerging Sources Citation Index (ESCI), Book Citation Index-Social Sciences & Humanities (BKCI-SSH), etc.)
7.	Countries and regions	All countries (The most articles are from USA, China, Italy, Pakistan, Saudi Arabia, France, Romania, etc.)
8.	Content of the articles	Articles that are related to the relevant research topic and that respect the searched keywords: "energy resources", "economic growth", "renewable consumption" and "CO_2 emissions".
9.	Methodological approach	Articles that include empirical research using statistical, econometric and quantitative analysis.
10.	Software	VOSviewer
11.	Database	Web of Science Core Collection because of this availability and its ability to capture the most relevant articles that are published in the scientific journals.

Source: Authors' own contribution based on the framework developed by Öztürk et al. (2024).

Results and discussions

The central objective of this paper was to conduct a systematic review of the existing literature that focuses on investigating and determining the impact of the consumption of various traditional and renewable energy sources on economic growth and pollution reduction in empirical studies using predominantly quantitative statistical or econometric methods and techniques.

Thus, the section dedicated to the results and their discussion from the point of view of the interdependencies between energy consumption, the use of renewable energy resources, economic growth and the reduction of pollution found in the existing research literature is divided into several sub-sections, in order to allow a better understanding of the subject dealt with following the bibliometric analysis carried out. The application of the selection criteria resulted in 971 studies that are relevant and successfully address the issues discussed in this article.

Analysis of academic publications by year and citations

The first sub-section presents the 971 scientific publications in a structured way, according to several criteria relating to the period analysed, the number and distribution of citations in this period, which aims to demonstrate the relevance and importance of this research field, which has been in full expansion and development since the formulation of environmental objectives, comprehensive environmental protection, pollution reduction, economic impact of energy transition to a clean and sustainable environment.

Unsurprisingly, there has been a recent and growing emphasis by academics and researchers on investigating the energy-pollution nexus and finding solutions and ways to reduce carbon dioxide emissions and promote a green and clean energy system at national, regional, EU and global levels. In addition, new research directions indicate that we are witnessing a permanent and challenging transition towards a circular economy, in which the increased use of renewable energy is a key pillar (Șahin et al., 2024; SantibanezGongalez et al., 2023; Huang et al., 2015).

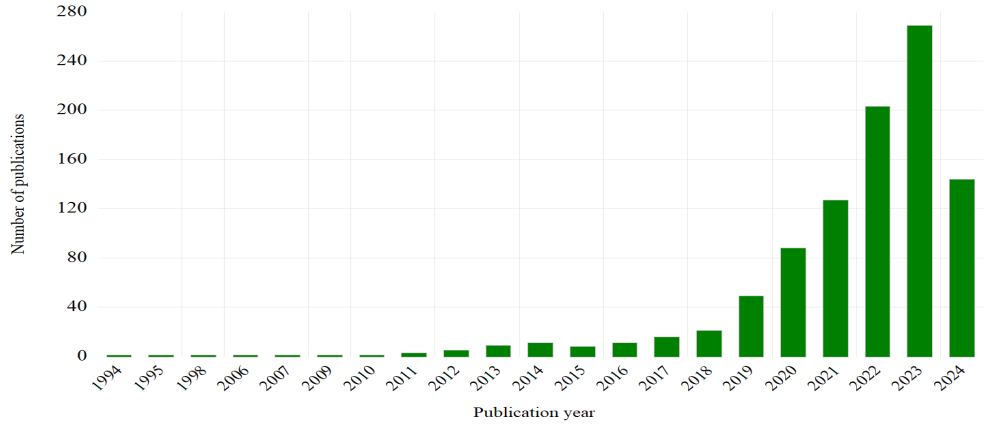

Figure 2. Distribution of the 971 academic articles by publication year

Source: Authors 'own contribution.

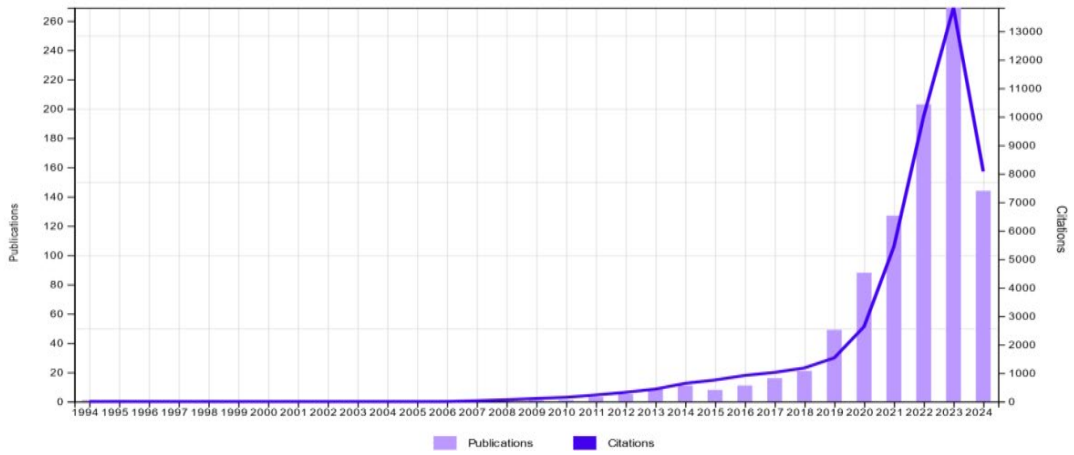

Figure 3. Distribution of 971 academic articles by citation over the time

Source: Authors 'owncontribution based on Web of Science Core Collection.

The first aspect analysed relates to the evolution and dynamics over time of the number of scientific publications and the number of citations on the subject dealt with in this study. The results presented in Figure 2 and Figure 3 show that 27.70% of the publications were written and indexed in 2023, which confirms the ever-increasing concern of researchers to contribute to the expansion and extension of the literature on the understanding of the interdependence between energy, environment, growth and/or economic development. This has also been maintained in the most recent period, with a total of 418 publications published in the period 2020-2022, where a common element was the impact of the Coronavirus pandemic on the energy system and, consequently, with negative and adverse effects on the economic mechanism.

Moreover, the first year in which a publication discussing our topic appeared is 1994, and during the whole period under analysis (in our case 1994-2024) a total number of more than 12500 citations was counted, most of them specific to the last 4 years, generating the up-date and popularization of the topic among researchers. Strictly analysing the year 2024, we can say that the positive and increasing trend is maintained and, up to that moment, the number of publications is 144, representing about 15% of the total number of publications indexed in Web of Science Core Collection related to the four keywords: "energy resources", "economic growth", "renewable consumption" and "CO_2 emissions". These aspects lead us to successfully validate the research question posed at the beginning of the article: *"How many publications deal with this topic, and which are the most relevant?"*

Scientific relevance analysis

In order to validate the second research question (*"What are the main practical and empirical issues found in these publications?")*, we set out to examine the 971 academic publications according to different research areas.

Figure 4 further demonstrates the distribution of the 971 scientific articles classified according to the specific category of inclusion in the Web of Science Core Collection. More than 40% of the publications are categorized as Environmental Sciences, followed by Environmental Studies and Green Sustainable Science Technology. This reflects the fact that pollution is a disruptive factor in the environment, where the high level of carbon dioxide emissions, mostly from the use of fossil fuels, is an issue that is increasingly being addressed in a multidisciplinary manner. For this reason, these articles can be included simultaneously in several specific categories of analysis; for example, 216 are included in Energy and Fuels, 69 in Economics, while 43 articles are specific to the Environmental Engineering category.

It is also very interesting to note that, to gain a comprehensive understanding of global issues, these energy-environment-growth interdependencies are analysed and discussed in relation to urban planning, thermodynamics, management, or interdisciplinary and multidisciplinary studies. It seeks to understand the interplay between social, economic, political, technological, environmental, cultural, and gender aspects of societal change at local, national, regional, and global levels, enabling the exploration of complex challenges such as poverty, inequality, environmental sustainability, and social justice from a global perspective (Aimer and Hamoudi, 2018; Behzadian et al., 2010; Balitskiy et al., 2016).

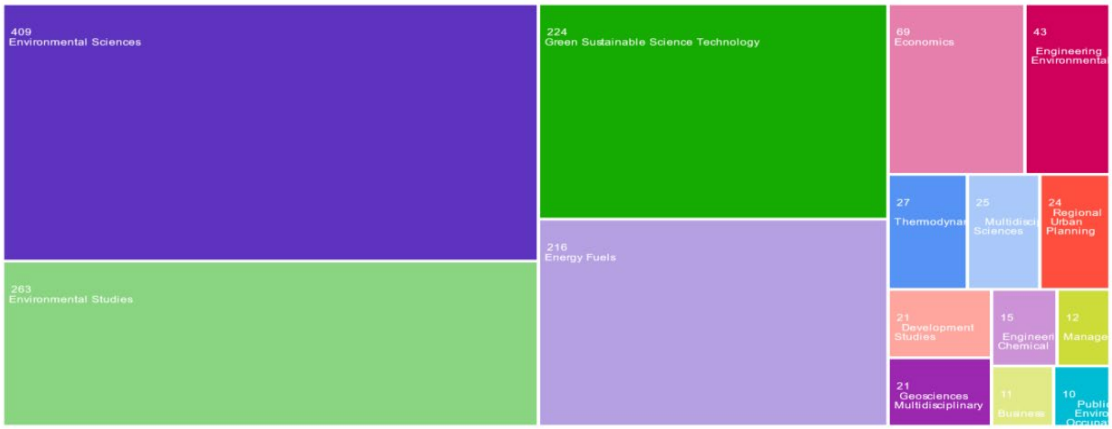

Figure 4. Tree map of the academic publications by Web of Science categories

Source: Authors 'own contribution based on Web of Science Core Collection.

Another aspect to be examined is the distribution of the resulting publications according to the form and type of publication, as well as the preferences and contributions of the researchers in this scientific field. According to the results presented in Table 2, we can see that the most common type of publication is the writing of scientific articles, which represents about 88% of the total number of publications, followed by review articles (about 4% of the total number of publications) and proceeding papers, with a share of more than 1.40% of the 971 publications indexed in the Web of Science Core Collection. As mentioned above, since 2018 and up to now, more and more publications have focused on analysing and investigating the set of relationships and linkages between energy, environment, and the overall economic system.

Table 2. Classification of the total number of Web of Science publications by document type

Document type	Number	Share in % of total publications
Article	920	87,95%
Review Article	41	3,92%
Proceeding Paper	15	1,43%
Book Chapter	2	0,19%
Retracted Publications	2	0,19%
Editorial Material	1	0,10%
Early Access	65	6,21%

Source: Authors 'own contribution.

The discussion of the results offered by these publications contributes decisively and primarily to new research directions, but above all to the generation of clear and coherent policies, actions, and tools to be used by government authorities, practitioners and decision-makers in the energy and economic sectors. It is no coincidence that the scientific literature has highlighted a number of hypotheses, such as growth, conservation, neutrality and feedbacks between the consumption of energy resources, economic growth and the level of carbon dioxide emissions (Balsalobre-Lorente et al., 2018; Balsalobre-Lorente et al., 2019; Dong et al., 2017;Mardani et al., 2019).They are all part of the traditional EKC hypothesis postulates that as per capita income rises, emissions first rise and then fall after reaching a maximum level (Grossman and Krueger, 1995; Shafik, 1994). Thus, the EKC hypothesis suggests an inverted U-shaped relationship between emissions and per capita income.

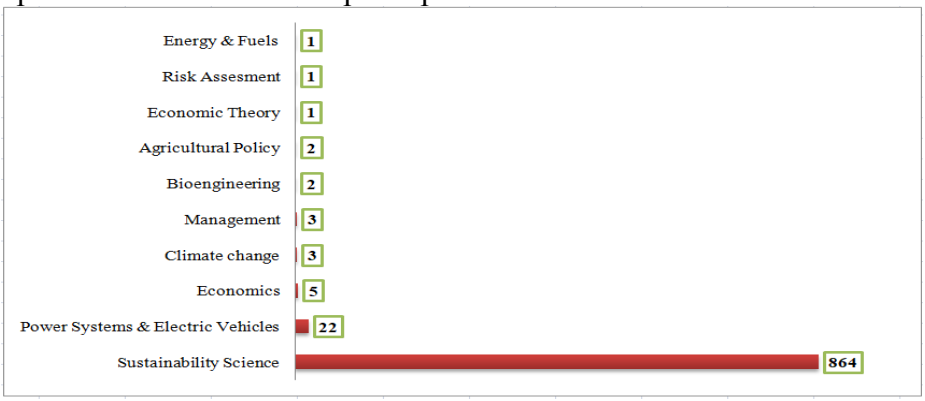

Figure 5. Distribution of academic publications according to topic area

Source: Authors 'own contribution.

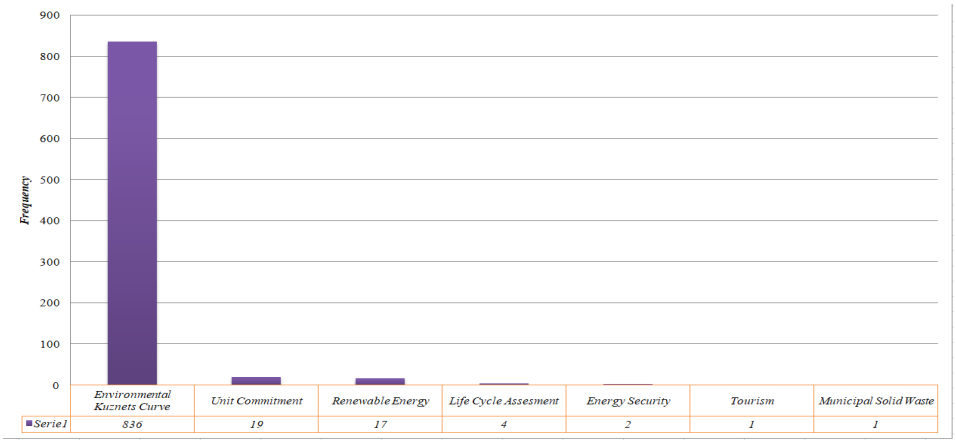

Figure 6. Distribution of the academic publications according to specific subjects

Source: Authors 'own contribution.

Specifically, the category "Sustainability Science", which discusses and analyses the issue of the "Environmental Kuznets Curve" from a microeconomic point of view, accounts for about 89% of the total number of publications at the macroeconomic level. The other scientific articles analyse issues related to "Renewable Energy", "Energy Security" or "Municipal Waste". They are classified at the macroeconomic level in the following categories: "Power Systems and Electric Vehicles", "Climate Change", "Management and Tourism", "Economics", and "Risk Assessment". The results presented in Figure 5 and Figure 6 thus show that the study of the causal relationships between the energy system, the economic system, and the environment (e.g. pollution reduction) requires a rigorous and detailed analysis by researchers using an interdisciplinary and multidisciplinary approach.

This shows that an increasing number of authors study the impact of pollution from multiple perspectives, emphasising economic growth, sustainable development, increased use of renewable energy resources and significant reduction of carbon dioxide emissions. Thus, a predominant use of statistical and econometric methods (e.g. panel analysis, cointegration analysis, time series analysis, multifactor regression, etc.) can be observed in the treatment of this topic, and the empirical and practical evidence obtained is becoming increasingly important for economic, energy and environmental policy makers.

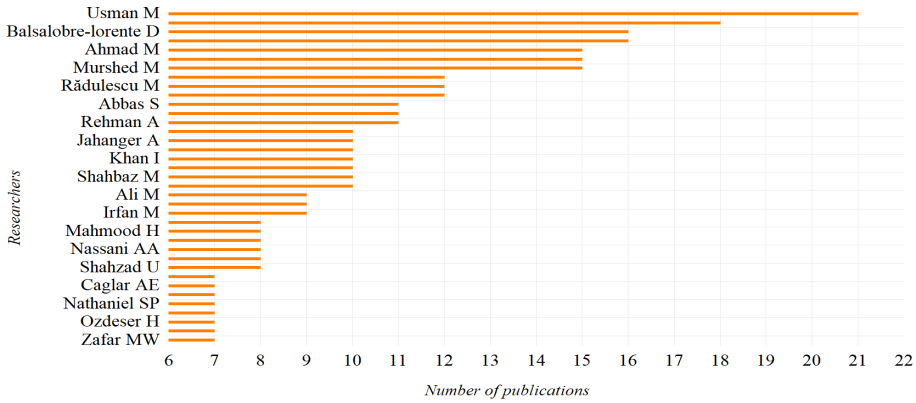

Figure 7. Top 10 researchers by contributions in this specific topic and subject

Source: Authors 'own contribution.

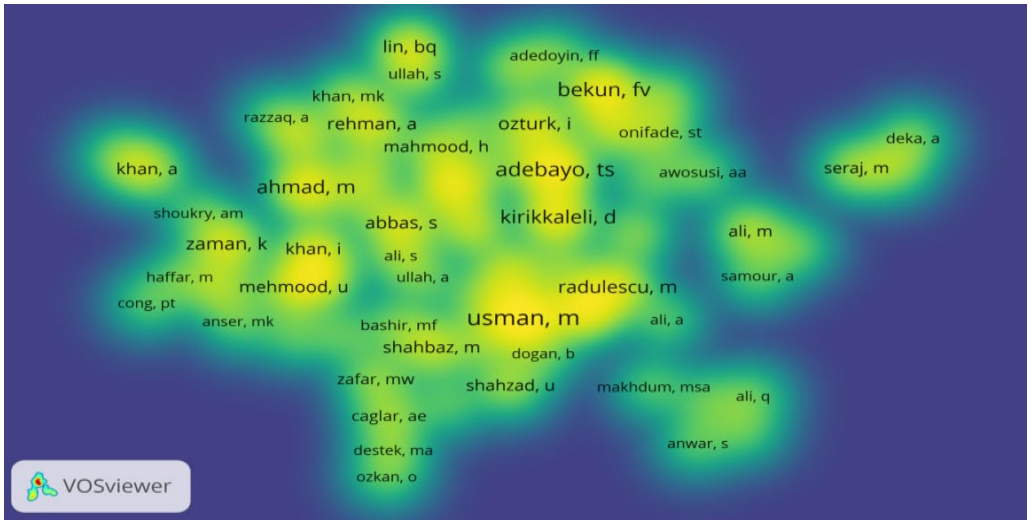

Figure 8. Density visualization of the researchers by contributions in this specific topic and subject
Source: Authors 'own contribution based on VOSviewer software.

On the other hand, we were interested in capturing the most valuable and consistent academics who have made notable contributions to this topic, so Figure 7presents a ranking of the top 10 researchers. We can see that Usman N (a total of 21 publications) is in first place, followed by Adebayo TS (18 publications) and Balsalobre-Lorente D and Bekun FV, who contributed a total of 16 publications each. In addition, the 5th place in this ranking is occupied by an important Romanian researcher, Rădulescu M, with a contribution of 12 publications in this field. According to this ranking, we can also see that the expansion and extension of this challenging research topic, which includes the keywords: "energy resources", "economic growth", "renewable consumption", and "CO_2 emissions", is not only possible by the individual contributions of each author, but rather by building collaborations and cooperation teams to treat the topic in the most professional, rigorous, detailed and innovative way in the coming years. Thus, by using VOSviewer, it was possible to identify a set of 8 clusters composed of the most representative authors and researchers in terms of their contributions to the study of the interdependence between energy consumption, economic growth, and environmental pollution.

According to Figure 8, it can be observed that there are these research partnerships created byfinding the best empirical evidence dealing with the topic at hand, as well as density visualization on a total number of 70 authors forming a total number of 216 links strength. In terms of the country of origin of the scientific papers analysed, most of them come from China, with 499 publications, i.e. more than 51% of the total. This is followed by Pakistan, with a total of 219 articles, and Türkiye, with 185 articles, or around 23% of the total. In addition, 33 scientific articles on the subject come from Romania, with a share of 3.40% of the total number of publications, which is higher than that of the USA (30 scientific articles) or Italy (21 scientific articles).

According to the affiliation of the authors and researchers, the most frequent research institutes and universities are the Lebanese American University, the Beijing Institute of Technology, the International University of Management and Administration, the Cyprus International University, Jiangsu University, as well as Istanbul Nisantasi University or Istanbul Gelisim University, accounting for more than 28% of the total number of analysed publications. These results are highlighted in Figure 9. Similarly, if we analyse the distribution of articles

according to the language of publication, 965 articles were published in English, followed by two in Turkish, two in Russian, and two in Chinese and Polish. This is quite natural, especially since English is the recommended language of writing in more than 95% of academic journals, and it is also a condition to be respected for the double peer review policy.

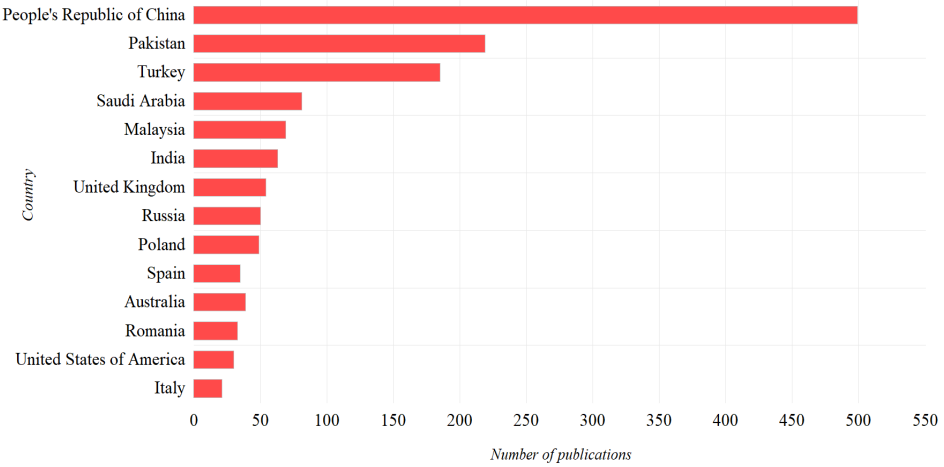

Figure 9. Distribution of academic articles by authors' origin and country

Source: Authors' own contribution.

On the other hand, the Web of Science is a highly relevant academic platform that generates systematic and consistent stringency and evaluation of academic journals according to their impact at a given point in time, the number of citations, research areas and the topics they integrate in their names and volumes. In our case, it can be observed that the most common research fields are those related to environmental sciences, ecology, energy and fuels, engineering, public administration, and business.

The main problems and empirical aspects found in the 971 articles studied were analysed, and the results obtained made it possible to highlight the most relevant contributions in the field, according to the importance of the countries, the contributions of the authors, the affiliations of these authors and the main approaches adopted in their scientific papers.

Furthermore, the validation of this research question could also be carried out according to other criteria specific to bibliometric analysis, among which we mention the journal of publication and its impact according to the performance indicators found in the academic platform Web of Science Core Collection, as well as the most frequently chosen academic publishers by the authors dealing with the interactions between energy, economy and environment.

Figure 10 therefore shows the specific academic journals indexed in the Web of Science Core Collection that deal with the links and interdependencies between energy consumption, economic growth, economic development, carbon dioxide emissions and the use of renewable energy.In this context, we note that 145 scientific articles were published in Environmental Science and Pollution Research, a journal listed in the Science Citation Index Expanded (SCIE) with an impact factor of 0.99 in 2023, published by the prestigious Springer. For example, more than 19% of the scientific papers are published in the journals Resources Policy and Renewable Energy, the Q1 Science Citation Index Expanded and Social Sciences Citation Index journals published by Elsevier, specializing in geography, planning and development, sociology and political science, economic geology, renewable energy, sustainability, econometrics and policy

and law. Other academic journals frequently chosen by researchers are Energy and Journal of Cleaner Production, both owned by Elsevier, with a share of around 6% of the total number of academic articles, and academic journals owned by the Swiss publisher Mdpi: Energies and Sustainability, with a total of 70 published articles (about 7% of the total number of articles considered) in our analysis.

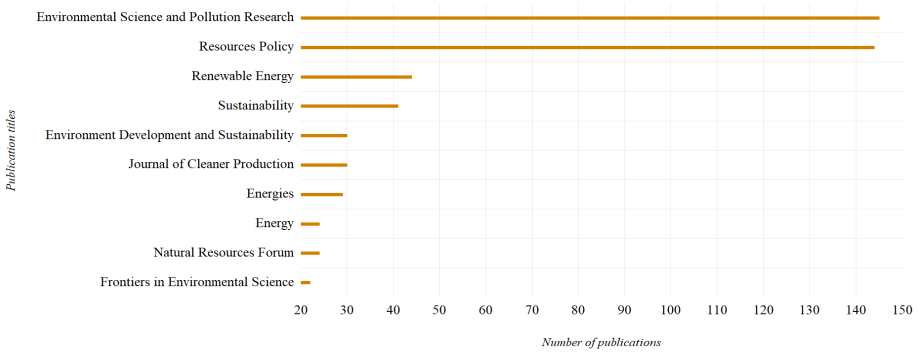

Figure 10. Distribution of academic articles published in the most important scientific journals

Source: Authors' own contribution.

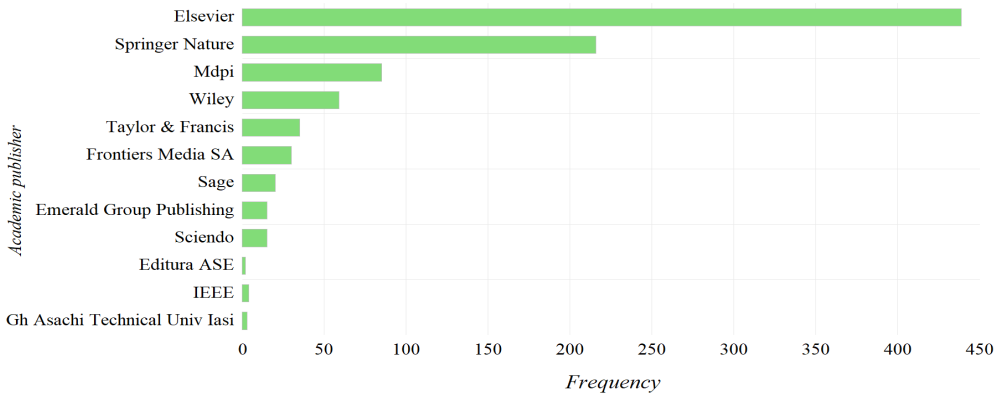

Figure 11. Distribution of academic articles by scientific publishers

Source: Authors' own contribution.

When analysing the scientific publishers (see Figure 11) that have produced the 971 articles, we find that Elsevier and Springer Nature occupy the top positions with a total number of 655 publications (about 67%), which indicates a high degree of relevance and reputation in terms of academic rigor and academic ethics. Furthermore, according to an analysis by Scopus, over 99% of Nobel laureates in science and economics have published in Elsevier journals since 2000.Also, Mdpi is another publisher preferred by the researchers, with 8.70% of the articles belonging to this publisher, while Willey, Taylor and Francis and Emerald Group Publishing occupy the middle places in terms of authors' preferences based on the prestigious publishers.

However, we are confident about the appetite of Romanian researchers in dealing with the environment-economy-energy nexus, considering that several 5 articles were published by ASE Publishing House in Bucharest and Gh. Asachi in Iași. Furthermore, of the 971 scientific articles, 178 are highly cited papers, 7 are considered "hot papers", and more than 65% of them are included in the Science Citation Index Expanded (SCIE), which is considered a highly important barometer of the most valuable and prestigious scientific journals, covering a wide range of topics with high impact on the academic world. Figure 12 shows that 550 scientific articles are

included in the Social Science Citation Index, another relevant indicator specific to high impact factor academic journals in the social sciences, arts, and humanities. A further 15 articles are proceedings papers included in the Conference Proceedings Citation Index-Science.

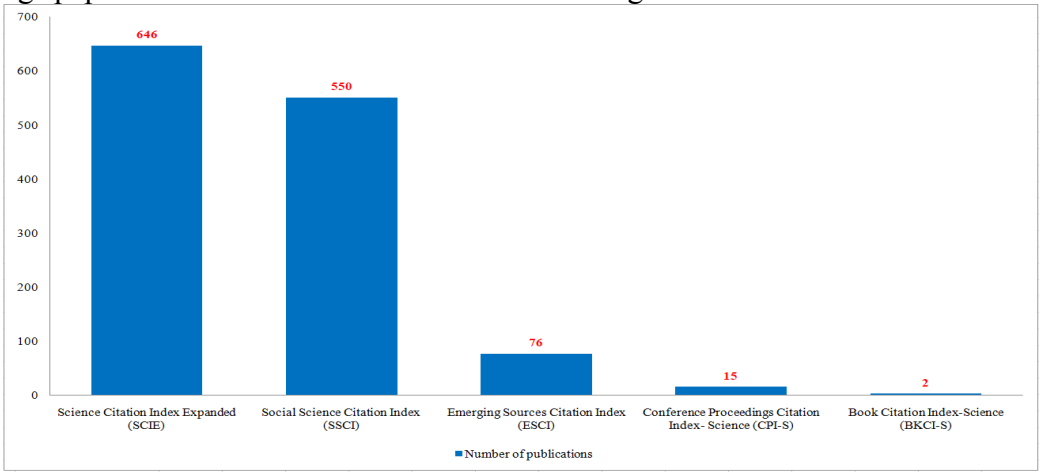

Figure 12. Distribution of academic articles by Web of Science Index

Source: Authors' own contribution.

In addition, we have made a ranking of the top 10 most cited scientific articles in the analysed period, most of them proposing innovative economic models and advanced econometric methods (e.g. panel analysis, quartile regression, machine learning algorithms, modified multifactor cointegration regressions - DOLS and FMOLS regressions) to study the interdependencies between the 4 key expressions: "energy resources", "economic growth", "renewable energy consumption", and "CO_2 emissions". The study by Lewis and Nocera (2006) is the most cited article in this direction with a total of 6905 citations, followed by the study performed by Balsalobre-Lorente et al. (2018) with 953 citations, and the study conducted by Bekun et al. (2019) with a total of 934 citations so far.The study conducted by Mardani et al. (2019) is ranked 10th in this ranking of the most cited articles, with a total number of 360 citations, where the central objective was to provide a comprehensive overview of the relationship between CO_2 emissions and economic growth, the results of this paper have shown that the relationship between CO_2 emissions and economic growth provides a rationale for policy options that need to reduce emissions by also constraining economic growth. The results of this ranking are presented in Table 3.

Table 3. The most cited academic articles according to the Web of Science

Title	Source	Authors	Citations	Rank
"Powering the planet: Chemical challenges in solar energy utilization"	Proceedings of the National Academy of Sciences of the United States of America; volume 103; issue 43; pp. 15729-15735; 2006	Lewis, N.S.and Nocera, D.G.	6905	1
"How economic growth, renewable electricity and natural resources contribute to CO_2 emissions?"	Energy Policy; volume 113; pp. 356-367; 2018	Balsalobre-Lorente, D.; Shahbaz, M.; Roubaud, D. and Farhani, S.	953	2
"Toward a sustainable environment: Nexus between CO_2 emissions, resource rent, renewable and non-	Science of the Total Environment; volume 657; pp.1023-1029; 2019	Bekun, F.V.; Alola, A.A. and Sarkodie, S.A.	934	3

Title	Source	Authors	Citations	Rank
renewable energy in 16-EU countries"				
"Energy models for demand forecasting-A review"	Renewable and Sustainable Energy Reviews; volume 16; issue 2; pp. 1223-1240; 2012	Suganthi, L., and Samuel, A.A.	783	4
"Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from organization for economic Co-operation and development countries"	Journal of Cleaner Production; volume 242; article no. 118537; 2020	Destek, M.A. and Sinha, A.	717	5
"Determinants of the ecological footprint: Role of renewable energy, natural resources, and urbanization"	Sustainable Cities and Society; volume 54; article no. 101996; 2020	Danish; Ulucak, R. and Khan, S.D.	685	6
"Effect of natural resources, renewable energy and economic development on CO_2 emissions in BRICS countries"	Science of the Total Environment; volume 678; pp. 632-638; 2019	Danish; Baloch, M.A.; Mahmood, N. and Zhang, J.W.	611	7
"The impact of natural resources, human capital, and foreign direct investment on the ecological footprint: The case of the United States"	Resources Policy; volume 63; article no. 101428; 2019	Zafar, M.W.; Zaidi, S.A.H.; Khan, N.R.; Mirza, F.M.; Hou, F.J. and Kirmani, S.A.A.	512	8
"The impact of natural resources, energy consumption, and population growth on environmental quality: Fresh evidence from the United States of America"	Science of the Total Environment; volume 754; article no. 142222; 2021	Khan, I.; Hou, F.J. and Le, H.P.	369	9
"Carbon dioxide (CO_2) emissions and economic growth: A systematic review of two decades of research from 1995 to 2017"	Science of the Total Environment; volume 649; pp.31-49; 2019	Mardani, A.; Streimikiene, D.; Cavallaro, F.; Loganathan, N. and Khoshoudi, M.	360	10

Source: Authors' own contribution.

At the same time, in our analysis we recorded the distribution of the 971 publications according to the 17 Sustainable Development Goals, which are integrated in the 2030 Agenda for Sustainable Development proposed by the Member States of the United Nations in 2015.This agenda offers a shared blueprint for peace and prosperity for people and the planet, now and in the future. It's centred on 17 Sustainable Development Goals (SDGs), which are an urgent call to action for all countries - developed and developing - in a global partnership. This agenda is an action plan for people, planet, and prosperity.

It also seeks to strengthen universal peace in greater freedom. The 17 goals and 169 targets will inspire action over the next fifteen years in areas of critical importance to humanity and the planet, at the national, regional, and global levels (United Nations, 2024; Halkos and Gkampoura, 2021; Fu et al., 2019; Khoshnava et al., 2019; FallahShayan et al., 2022; Ordonez-Ponce, 2023).

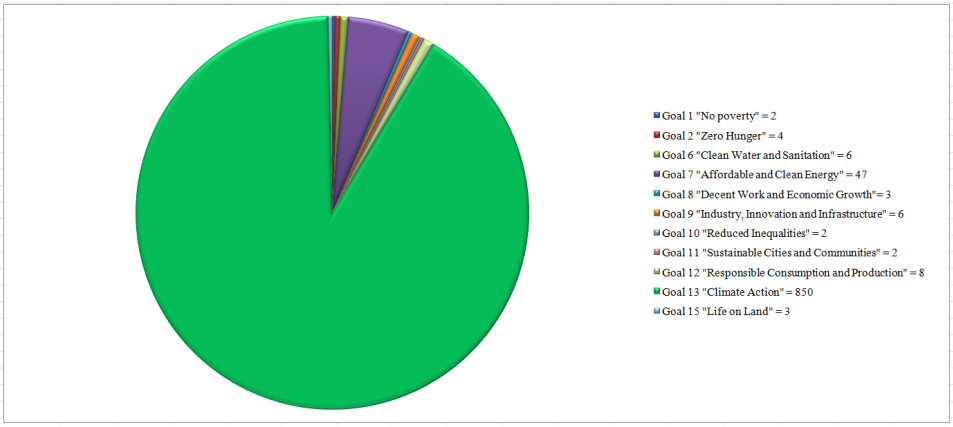

Figure 13. Distribution of scientific articles by Sustainable Development Goals

Source: Authors' own contribution.

As expected, 88% of the total number of publications fall under "*Objective 13 - Climate Action*", which states that reducing pollution is an essential first step in the fight against climate change and that through education, innovation and meeting our climate commitments we can make the changes necessary to protect the planet. Therefore, these articles offer comprehensive solutions and actions to understand the causality between carbon emissions, economic growth, and energy consumption; to integrate climate change measures into national policies, strategies, and planning; and to improve education, awareness and human and institutional capacity for climate change mitigation, adaptation, impact reduction and early warning (Abumunshar et al., 2020; Bekun et al., 2019; Bilgili et al., 2016; Izanloo et al., 2021). The other 12% of publications integrate related Sustainable Development Goals. These relate to affordable and clean energy (Goal 7), decent work and economic growth (Goal 8), and responsible consumption and production (Goal 12). The results are illustrated and presented in Figure 13.

Bibliometric assessment: Co-authors and Co-word analysis

Another aspect of the present study is to establish and visualize the relationships between the main keywords appearing in the 971 publications in the Web of Science Core Collection. To achieve this, we used the VOSviewer software to analyse the number of publications that were focused on the four keywords: "energy resources", "economic growth", "renewable consumption", and "CO_2 emissions".

The bibliometric analysis carried out in this study allowed us to understand the importance and relevance of the topic under discussion in the existing literature, using two specific procedures: the procedure of social co-authorship analysis, and the structural and conceptual procedure based on co-word analysis. The main aim of these two procedures was to understand how the authors have positioned themselves in relation to this research topic and, in particular, how they have explored the links between energy consumption, renewable energy resources, economic growth and carbon emissions.

The VOSviewer software is used to create network visualizations. The size of the nodes and words in the graph is a function of how much weight they have. The weight increases as the frequency of nodes and words increases. Nodes with the same colour are grouped into clusters. The colours indicate how closely two keywords are related. The distance between two nodes shows how strong their relationship is. Line length explains the relationship between the two words, and line thickness emphasizes the degree of their co-occurrence. (Stratone, 2023; Lim and

Kumar, 2024). VOSviewer displays the keywords "energy resources", "economic growth", "renewable consumption", and "CO_2 emissions" in academic publications in nine clusters.

Figure 14. The main clusters on the most relevant keywords identified in the academic publications
Source: Authors' own contribution based on VOSviewer software.

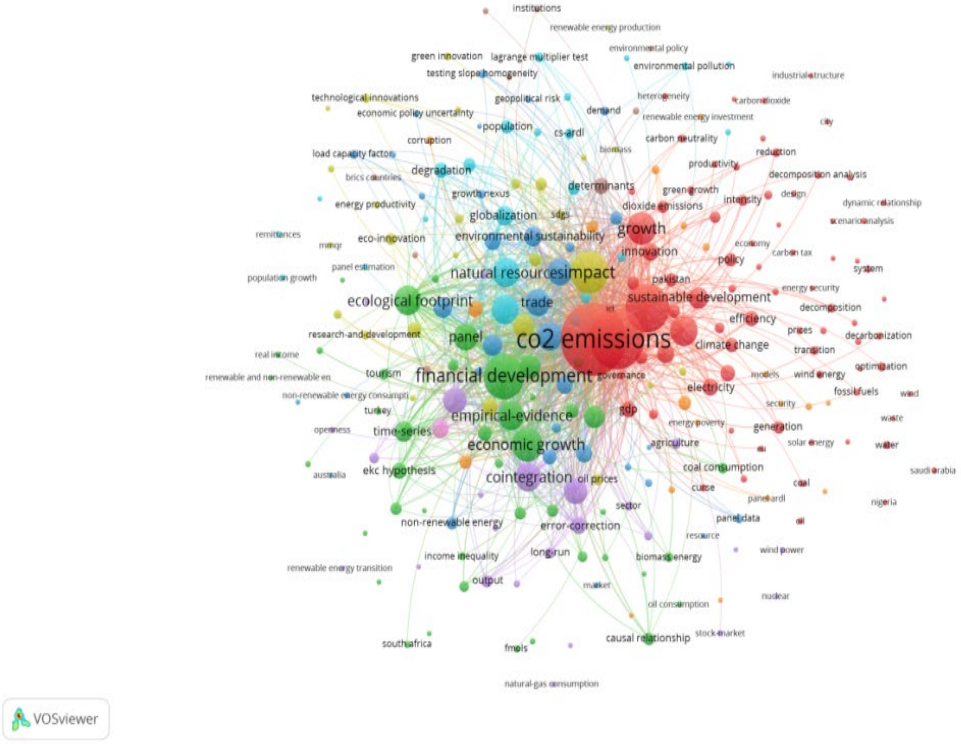

Figure 15. Links and occurrences between all the keywords from the academic publications
Source: Authors' own contribution based on VOSviewer software.

Figure 14 shows the 9 clusters that have been created according to the key terms found in each of the 971 publications, while Figure 15 visualizes the nodes and links that have been created between these terms after the application of VOSViewer. The main findings are as follows:

- Cluster 1 contains 80 keywords and focuses mainly on the promotion of a clean sustainable environment, green energy, and the significant reduction of carbon emissions. In addition, the most common terms were "carbon neutrality"; "decarbonization"; "energy transition"; "climate change"; "energy security". There is also an increasing emphasis on empirical evidence in the context of "EU"; "China"; "Pakistan" or "developing countries", as well as on the use of advanced econometric methods to achieve the central objectives of these academic articles: "quartile regression", "scenario analysis"; "decomposition analysis". At the same time, we find the realization of analyses involving the impact of carbon dioxide emissions and "GDP"; "growth"; "green growth".
- The second cluster contains a set of 43 keywords and aims to investigate and empirically prove the EKC hypothesis. In this sense, more and more studies apply "causality analysis"; "ARDL method"; "machine learning", leading to "new evidence" on "economic growth nexus", "ecological footprint" and "energy consumption".
- Cluster 3 is made up of 33 keywords and includes academic publications dealing with the use of renewable energy resources, which are seen as an important factor in promoting a clean and sustainable environment. The most frequently used terms are "clean energy"; "economic globalization"; "environmental sustainability". In this cluster, the most frequently used econometric methods are panel econometric methods: "panel quantile regression"; "panel cointegration regressions".
- A total of 24 keywords forms Cluster 4, which brings forward challenging issues and reflections at the heart of promoting the circular economy through "green innovation", "research and development", "eco-innovation", and "technological innovation".
- The next two clusters (Cluster 5 - 24 keywords and Cluster 6 - 23 keywords) aim to investigate the long-term causal relationships between pollution, financial development, economic development, and energy intensity. The econometric methods used are diverse and take the form of "panel estimation", "STIRPAT model", "error correction model", considering explanatory variables such as: "urbanization", "industrialization", "energy consumption", "population growth", or "life expectancy."
- Cluster 7 comprises a total of 19 keywords and offers a broader spectrum to examine the interdependencies between economic growth, energy consumption and environmental pollution by including new explanatory variables such as "corruption", "energy investment", "energy poverty", "foreign direct investment" or "institutional quality". The used methods remain in the field of "panel data analysis", but the empirical evidence is found in "Asian countries", "G7 countries" and "emerging countries and economies".
- The last two clusters (Cluster 8 and Cluster 9), comprising a total of 10 keywords, aim at studying environmental degradation from an economic perspective by applying panel cointegration methods. The main terms are: "economic complexity", "environmental policy", and "financial globalization".

At the same time, Figure 16 and Table 4 show the most important terms through which links and associations are made within each cluster. Thus, "CO_2 emissions" is the most frequent term in cluster 1 (5789 total link strengths); "ecological footprint" is the most frequent term in the second cluster, while in cluster 3 the term "non-renewable energy" appears 27 times, with a total

link strength of 227 times. The terms "globalization", "cointegration", and "impact" are three other terms that appear most frequently in clusters 4, 5 and 6 respectively. The keyword "institutional quality" is the most representative for cluster 7, with a total number of links and nodes of 325. For clusters 8 and 9, the terms "innovation", and "environmental degradation" have been identified, appearing 40 and 53 times respectively, and forming strong links with the other keywords in the remaining clusters.

According to the results obtained, we can provide answers to the following research question, namely: *"Can clusters be identified in terms of the most important keywords and scientific information found in these academic publications?"*

This bibliometric analysis and the discussion of the results have made it possible to identify, demonstrate and substantiate the impact of energy consumption on economic growth and development, where environmental pressure is a topical and increasingly widespread global issue. Thus, the study of these interdependencies, by providing clear and empirical evidence, will inevitably lead in the future to the constitution of new innovative models for the study and application of sophisticated econometric methods, where the reduction of pollution and the transition to a renewable energy system are the essential pillars for the protection and guarantee of a sustainable environment.

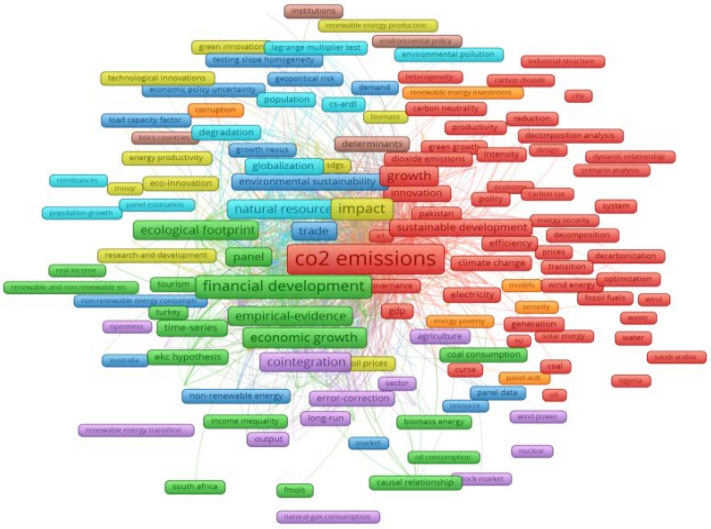

Figure 16. The co-occurrences of the keywords identified in the academic publications

Source: Authors' own contribution based on VOSviewer software.

Table 4. The most representative terms for each cluster

Cluster	Relevant keywords	Links	Total link strength	Occurrences
Cluster 1	Carbon; Carbon dioxide; Carbon neutrality; Carbon tax	22; 34; 43; 31	25; 45; 78; 37	6; 6; 11; 6
	CO_2 emissions	258	5789	773
	Consumption	247	2648	344
	Decarbonization	39	61	9
	Decomposition; decomposition analysis	55; 36	88; 63	14; 9
	Dioxide emissions; emissions	84; 82	199; 162	25; 27
	Dynamic relationships; economy; efficiency	31; 33; 102	56; 42; 264	7; 6; 37
	Electricity; electricity production	120; 29	340; 35	43; 5

Cluster	Relevant keywords	Links	Total link strength	Occurrences
	Energy; energy demand; energy policy; energy resources; energy security; energy transition	119; 48; 37; 17; 20; 78	266; 68; 52; 26; 31; 169	39; 8; 8; 5; 5; 21
	Environment; environmental impact; environmental regulations; climate change; global warming	92; 29; 27; 111; 27	229; 36; 38; 231; 37	28; 5; 5; 32; 7
	EU; China; Africa; Nigeria; Pakistan; Saudi Arabia; Developing countries	38; 189; 95; 24; 80; 24; 41	55; 1005; 223; 29; 212; 40; 60	7; 138; 28; 5; 227; 6; 8
	GDP; growth; green growth; governance; mitigation; policy	113; 189; 48; 53; 31; 91	320; 1158; 70; 80; 40; 217	38; 151; 10; 10; 6; 29
	Industrial structure; industry; ICT; innovation; investment; performance; productivity; prices	24; 50; 35; 123; 71; 63; 47; 37	38; 91; 56; 398; 135; 109; 74; 55	5; 14; 7; 49; 16; 17; 9; 8
	Oil; solar energy; water; wind energy	34; 30; 34; 48	50; 40; 48; 74	6; 6; 10; 10
	Renewable energy; renewable energy sources	257; 35	4021; 48	527; 8
	Method of moments quantile regression; scenario analysis	34; 25	49; 41	6; 7
	Sustainability; sustainable development; sustainable energy; transition	134; 163; 47; 59	400; 549; 71; 96	52; 69; 9; 13
Cluster 2	Carbon footprint; ecological footprint	47; 171	83; 1103	10; 133
	Causal relationship; causality analysis; dynamic impact; Granger causality; time-series	70; 37; 37 ; 65; 128	207; 64; 66; 155	25; 8; 8; 18
	ARDL; DOLS; Dynamic ARDL; Dynamic ARDL simulations; FMOLS; Machine learning	75; 37; 33; 32; 44; 27	206; 53; 47; 49; 71; 36; 531	23; 6; 5; 5; 8; 5; 64
	Economic growth; economic-growth nexus	200; 96	1433; 222	175; 26
	EKC hypothesis; empirical evidence; fresh evidence; Kuznets curve hypothesis	111; 182; 93; 107	344; 973; 198; 317	39; 121; 24; 37
	Energy consumption; oil consumption; renewable and non-renewable energy	150; 35;31	613; 49; 44	76; 6; 5
	Mitigate CO_2 emissions; pollution haven hypothesis	36; 62	46; 130	5; 18
	Real GDP; real income	49; 41	67; 60	6; 7
	Tourism; trade openness	71; 155	151; 680	18; 84
Cluster 3	Clean energy; non-renewable energy; non-renewable energy consumption; renewable energy consumption	54; 89; 38; 140	88; 227; 60; 540	12; 27; 7; 70
	Demand; growth nexus; market	57; 54; 33	107; 100; 47	14; 12; 6
	Economic globalization; economic policy uncertainty; geopolitical risk	34; 45; 41	66; 76; 63	7; 8; 9
	Environmental sustainability	128	463	59
	Greenhouse gas emissions	45	79	11
	Heterogenous panels; load capacity factor; nexus; inference; panel cointegration; panel data	46; 45; 180; 75; 112; 59	82; 109; 923; 150; 309; 121	8; 13; 114; 16; 36; 13
	Panel econometrics; panel quantile regression; regression; unit-root tests	32; 51; 88; 113	44; 78; 235; 375	5; 9; 29; 47

Cluster	Relevant keywords	Links	Total link strength	Occurrences
Cluster 4	Causality; footprint; impact; quantile regression	130; 30; 233; 89	366; 43; 2056; 197	44; 6; 257; 25
	Circular economy; sustainable environment	54; 64	82; 124	11; 15
	Eco-innovation; energy productivity; fintech	70; 35; 28	155; 57; 38	20; 8; 5
	Green energy; green innovation; research-and-development; technological innovation	36; 45; 53; 112	53; 75; 113; 309	6; 10; 14; 35
	International trade	34	53	7
	Oil prices	68	135	18
	Pollution	86	223	28
	Renewable energy production	24	35	5
Cluster 5	Agriculture; natural resource	66; 47	126; 74	17; 10
	Carbon dioxide emissions; Carbon intensity	73; 20	150; 27	18; 5
	Cointegration; long-run; error-correction	180; 60; 119	1064; 142; 391	126; 18; 46
	Education	39	69	8
	Natural-gas consumption; electricity consumption; renewable electricity	30; 165; 37	40; 811; 49	5; 103; 7
	Stock-market	31	46	6
	Sector	58	110	14
	Sustainable development goals	63	117	13
Cluster 6	Air pollution; degradation; environmental pollution	28; 92; 53	37; 285; 92	5; 34; 11
	Cross-sectional dependence; dependence	30; 63	42; 123	6; 14
	Economic development	63	128	18
	Energy intensity; energy use	42; 47	70; 83	10; 11
	Financial inclusion; globalization; industrialization; urbanization; technology	32; 132; 78; 189; 81	43; 417; 183; 1143; 202	5; 60; 21; 133; 25
	Human capital; life expectancy; population; population growth	97; 37; 87; 31	269; 55; 221; 46	29; 7; 28; 6
	Panel estimation; STIRPAT model	40; 33	62; 46	7; 6
Cluster 7	Corruption	42	78	10
	Emerging economies; Asian economies; G7 countries	42; 21; 48	67; 27; 66	8; 5; 8
	Energy efficiency; energy poverty; renewable energy investment	85; 30; 29	194; 42; 44	30; 6; 6
	Environmental quality	82	212	27
	Green finance	48	94	12
	Foreign direct investments	86	193	24
	Institutional quality	106	325	40
	Management	37	52	10
	Panel data analysis; panel ARDL	32; 34	43; 50	5; 6
	Resource efficiency	22	35	5
	Security	37	53	7
Cluster 8	Economic complexity	36	60	7
	Environmental policy	30	49	5
	Financial globalization	35	55	6
	Green technology innovation	49	71	7
	Empirical analysis; BRICS countries	40; 34	68; 56	9; 7
Cluster 9	Environmental degradation	111	409	53

Source: Authors' own contribution based on VOSviewer software.

The main contribution of our study was to investigate the relationships and linkages between different traditional and renewable energy sources, economic growth and pollution by applying and providing a rigorous and detailed analysis of the existing research field.

However, bibliometric analysis has the capacity not only to highlight, determine and interpret the results found in existing research, but also to guide the author towards new directions, recommendations and suggestions for research on the topic. Thus, through the research question posed:*"What are the main future directions to be pursued by identifying these keywords and connections/relationships between them?"*, we can suggest that the interdependent relationships between energy, economic growth and environmental pollution are constantly being explored and new and innovative ways of analysis are being found.

In the current period, most countries are increasingly concerned with energy diversification through renewable energy sources. For this reason, the literature attempts to demonstrate and highlight the positive effects of renewable energy use on both economic growth and development and on the environment. Renewable energy is seen as a viable option and an important solution for protecting the natural environment, which can systematically contribute to a significant reduction in carbon dioxide emissions, thus helping to reduce pollution. One example is the study by Wang et al. (2022), which analyses the impact of renewable energy sources on economic development in 34 OECD countries between 1997 and 2015.

The contribution of this study is to examine the causal relationships from the perspective of the management of different types of risk, from composite risk, country risk, political-economic risk and financial risk. One of the findings of this study is that countries with a lower composite risk generally have a more stable environment, and the use of renewable energy is more supportive of economic development.

Similarly, the results obtained by Jia et al. (2023) showed that renewable energy contributes to economic growth in the 90 countries participating in the Belt and Road Initiative (i.e. major energy consuming and importing countries) in the period 2000-2019. It also tested and confirmed the feedback hypothesis by applying Granger causality tests and showed that renewable energy consumption has a positive and direct impact on gross investment, FDI inflows, employment and trade. The main recommendation following the analysis conducted in this study is the promotion of renewable energy, which can lead to sustainable economic growth and export enhancement within the BRI (Belt and Road Initiative) countries.

Apergis and Danuletiu (2014) advocate the creation and design of these government policies to improve the energy sector and increase the use of renewable energy sources, which are considered important tools for economic growth and development. The analysis carried out revealed the existence of a long-run bidirectional causal relationship between energy resources and economic growth through the application of the panel cointegration error correction model at the level of the 80 countries divided by geographical region (i.e. European Union, Western Europe, Asia, Latin America and Africa) in the period 1990-2012.

According to the bibliometric analysis carried out, a number of implications can be identified for the transition to a cleaner and greener environment, where increasing the use of renewable energy sources is a viable policy measure in this endeavour. In particular, current long-term environmental objectives are based on a significant reduction of carbon dioxide emissions. In practice, an increasing number of EU Member States are committed to climate neutrality through national policies and strategies.

For example, the most common policy measures are aimed at reducing these carbon dioxide emissions in most key sectors (e.g. transport, energy, agriculture, industry, etc.). Another

measure aimed at reducing the carbon footprint, which can be achieved by applying additional taxation, is suggested by the effects of taxation on pollution, which generates burden emissions of various harmful substances: solid waste, wastewater, air pollution, hazardous chemicals and noise.

Another implication of our study is the positive impact of decarbonisation, a solution that creates efficiencies and opens up markets for low-emission products and services. An efficient and effective way to combat climate change, biodiversity loss and pollution is to tax sources of pollution and greenhouse gas emissions. Revenue mobilisation and redistribution can also be achieved through environmental taxes. In this context, we note that a price on carbon is a cost-effective way of reducing emissions, providing incentives for households and businesses to reduce their use of carbon-intensive energy and to switch to cleaner fuels, while at the same time mobilising government revenues (OECD, 2024).

On the other hand, an environmental policy solution that focuses on increasing the use of renewable energy sources is proposed by the model of the circular economy. Much of the focus of the circular economy is on materials management and ensuring that resource cycles are closed, similar to natural ecosystems where water and nutrients are continuously recycled (Gladek, 2020). The circular economy also aims for energy efficiency. Energy is produced exclusively from renewable resources.

Specifically, a future direction of research could be to increase people's awareness of the negative effects of pollution. Through actions, programmes and policies in the fields of education and health, people can better learn how they can contribute to the protection of the environment, how they can become more aware of the risks they are exposed to and how they can protect themselves against these risks. For this reason, new research must examine the interactions between pollution and the environment by integrating those variables related to human actions and behaviour. For example, future studies can make a significant contribution to the fight against pollution by including variables that measure health, education, environmental quality, resource efficiency or institutional quality.

Conclusion

The aim of this study was to carry out a detailed literature review on the study of the relationships between energy consumption, economic activity, and pollution. For this purpose, we chose bibliometric analysis as a quantitative research method that could be applied to the 971 scientific publications indexed in the Web of Science Core Collection on this subject. The database was based on all publications referring to the following terms: “energy resources”, “economic growth”, “renewable consumption”, and “CO_2 emissions” and it was performed on 9 August 2024.

The results show that an increasing number of authors are concerned and interested in studying these causal relationships in the short and long term, but with a particular inclination towards anything that promotes a clean, non-polluting environment through comprehensive climate action. Moreover, the number of publications increases significantly in the period 2018-2023, an increasing trend that is maintained in 2024, when 971 academic publications are included in the Web of Science at the time of the search. Another interesting aspect that emerged from the analysis is confirmed by the authors' contributions to the extension and expansion of the specific research field of “sustainability science”, where the most preferred topics relate to providing empirical evidence on the EKC hypothesis, renewable energy, energy security, urban

planning, tourism, and green and eco-innovations (Shafik, 1994; Jahangir and Dural, 2018; Kalyoncu et al., 2013; Kaplan et al., 2011; Grigore, 2023).

On the other hand, by using the specific bibliometric analysis tool VOSviewer, a set of 9 clusters consisting of 259 most used and frequently found keywords in the analyzed academic publications was found. In this way, it was possible to highlight the relationships and connections between these keywords, as well as the frequency of occurrence and the degree of strength established at the level of the 9 clusters. At the same time, we have noticed that more than 95% of these publications offer empirical explanations that follow the construction of economic models using diverse and complex econometric methods, the most common of which are: multifactor regression, panel data regression, cointegration regression, vector error correction model, ARDL model. The last two clusters offer new perspectives to study the causal relationships between energy consumption, economic growth, and pollution by building complex models that integrate other explanatory variables such as industrialization, urbanization, population growth, financial development, corruption or education and training. This climate change trend can also be realized by moving from the current economic system to a circular one, where recycling, reuse, non-conventional energy use (i.e. renewable energy) are promoted, all aiming at a more accentuated ecological footprint (Østergaard et al., 2020; Park and Hong, 2013; Pirlogea and Cicea, 2012; Bilgili et al., 2016).

Practical recommendations

This article can represent a guide to follow the direction of research on the association relationships between economic growth, conventional energy, renewable energy, and pollution, providing a broad and detailed framework to review the scientific literature in a systematic and reported way on a series of necessary elements from a theoretical to an empirical and practical prism.

The visualization of the 9 clusters on the associations and connections between the analyzed keywords has a practical character for future researchers, academics, and policy makers to study the phenomenon of sustainable environment and green energy in a multidisciplinary way. In addition, climate change and environmental pollution are topical issues that are increasingly found and analyzed in the 971 publications from the Web of Science Core Collection, which makes us realize that actions in the fields of environmental policy, energy mix, financial development and energy security will become the central pillars to ensure a sustainable economic environment with a high footprint towards greening and consistent reduction of carbon emissions.

However, considering that a relevant function of bibliometric analysis is to explain current trends in a particular field of research or on a particular topic, we can make a number of recommendations and suggestions for future research directions. Although the interdependencies between energy, the economy and pollution have been studied for a long time, we believe that there is a need to better study the impact of renewable energy on economic activity and the environment.

Specifically, statistical and econometric models can be built to test and evaluate how these non-conventional energy sources generate positive effects in reducing carbon footprints and achieving climate neutrality. In addition, such analysis can be useful and beneficial to energy, economic and environmental policy makers, so that pollution pricing is a viable policy measure on the road to decarbonisation.

At the same time, another direction of study can be suggested by examining the interdependencies between renewable energy sources, economic growth and pollution from the perspective of public awareness, where a series of policies in the education and health sectors can be constituted. Furthermore, the examination of these interdependencies can include variables such as financial development, green finance, the dynamics of investment flows or financial and monetary stability.

Limitations

There are some limitations to this study. These result from the exclusive use of the Web of Science Core Collection database, which restricted the number of scientific studies. A possible specific limitation of the analysis carried out in this study stems from the database used to search for scientific articles containing the terms: "energy resources", "economic growth", "renewable consumption", and "CO_2emissions".

The choice of databases may affect the accuracy and completeness of search results, as different databases may have different coverage and indexing methods. Although Web of Science remains one of the most relevant platforms in terms of providing scientific literature in various and diverse fields and research interests, we are aware of the existence of other databases in this regard and will therefore include them in future studies, such as Scopus, Science Direct, Springer Link or Elsevier database.

However, bibliometric analysis has advantages in predicting the future trends of disciplines and is widely used to analyze the research status, frontiers and development trends of specific disciplines, a further limitation may be due to the drawbacks of this quantitative method of research. In this respect, bibliometric analysis may not capture cross-disciplinary indicators, limiting its ability to identify research gaps in interdisciplinary areas. In addition, the analysis is limited to the data available in the selected database and may miss important research from other sources (Lim and Kumar, 2024; Donthu et al., 2021; Merediz-Solà and Bariviera, 2019). Against this background, a possible future direction of study would be to conduct an analysis of the opportunities and benefits that energy transition offers for a clean and sustainable environment.

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