New insight into the Bibliometric Analysis on the Topic of Environmental Kuznets Curve

Libo Xia[1*], *Zhiliang* Wang[2], *Shuang* Du[1], *Decun* Tian[2] and *Sujun* Zhao[3]

[1]North China University of Water Resources and Electric Power, School of Environmental and Municipal Engineering,450045, Zhengzhou, China
[2]North China University of Water Resources and Electric Power, College of Water Resources,450045, Zhengzhou, China
[3]The People's Hospital of Jianshui,654300, Honghe, China

Abstract. The topic of the environmental Kuznets curve (EKC) was searched on Web of Science and 2,747 documents were obtained from 2010 to 2020. Among them, 2616 documents were selected and analysed using the bibliometrix package in the R language. Results showed that Environmental Science and Pollution Research were the most literature sources, and the country with the most researches was China. Keywords analysis revealed that most researches were focused on the EKC, economic development, and carbon dioxide (CO2) emission, and the last item was the main environmental pollution problem. Most researches were focused on income distribution, benefits, ecological footprint, globalization, and degradation evidence. Dividing these documents into three stages with 2014 and 2018 as the nodes, economic growth was focused from 2010 to 2014, following was focused on emissions and then the international tourism from 2019 to 2020. EKC was easily visualized among the co-citation network of authors, the co-occurrence network of keywords and the cooperation network of countries. EKC historical graph showed that the global environment should be considered as a whole to research environmental pollution and economic development, and more research should be focused on the EKC related to clean energy and sustainable development. Therefore, by analysing a large number of documents and using scientific measurement methods, it is convenient for future research on the EKC hypothesis.

1 Introduction

The problem between environmental pollution and economic development has always existed. It was proposed that as the labour force shifted from low-income agriculture to high-income industries, the process of industrialization led to increased income inequality, and at a more advanced level of development, inequality began to decrease [1]. The data from multiple countries were used to find that the per capita emissions of pollutants have an inverted-U relationship with per capita GDP [2]. According to the relationship between various environmental indicators and the level of per capita income, the environmental conditions brought an initial stage of deterioration with economic growth and then began to improve. Later, this situation was called environmental Kuznets curve [3]. The environmental Kuznets curve (EKC) related literature was summarized, including theoretical development and empirical research on the EKC phenomenon, and found that EKC had problems [4]. The new model helps to understand the true relationship between economic development and the environment and may lead to the demise of the classic EKC [5]. The results showed that energy consumption and control of carbon dioxide emissions may not have an impact on Turkey's economic growth, and used a linear logarithmic model to point out that the EKC hypothesis is invalid [6]. Carbon dioxide emissions have a strong relationship with energy consumption and foreign investment which, also supports the EKC hypothesis [7]. The panel data such as carbon dioxide emissions, per capita GDP, population density, land, and industry's share of GDP were studied the EKC hypothesis of 14 Asian countries, which was an EKC hypothesis that provided empirical support [8]. The causal relationship among energy consumption, carbon dioxide emissions, economic growth, trade opening, and urbanization in EU states were investigated and provided evidence to support the EKC hypothesis [9]. The relationship between environmental pollution and economic development is still under study.

Bibliometric analysis is to scientifically determine the relationship between related fields of thesis research by analysing a large number of related documents. According to the defined coupling standards, the automatic processing results of a large number of scientific papers were described, showing the logic between the papers [10]. The network of co-cited papers and co-occurrence data can become a specific scientific discipline and provide a new method for article indexing. [11]. A method that analyses the evolution of topics in a specific research field can allow us to quantify and visualize the evolution of topics in a specific research field [12]. There are already some bibliometric analyses on environmental pollution issues. The relationship between energy growth and discuss future research directions and emerging trends was analysed by the

* Corresponding author: 201514321@stu.ncwu.edu.cn

CiteSpace (https://citespace.podia.com/) software [13]. And the VOS viewer software (https://www.vosviewer.com/) and meta-analysis methods were used to track the historical trends of the topic studied the author's contribution, and transformed the network analysis into a visual form [14]. There were 4,225 articles on haze and economic growth as the research object, and the CiteSpace software was used to explore the spatial and temporal distribution of literature. [15]. By using the bibliographic analysis of the Web of Science (https://www.webofscience.com/) to give a detailed overview of the EKC hypothesis. [16]. The bibliometrix package in the R language [17] for the research of comprehensive bibliometric analysis [18]. This article will use the method of bibliometric analysis to analyse 2,616 articles from the Web of Science, and conduct co-citation, co-occurrence and co-word analysis on the articles. Through the use of scientific methods to analyse the relationship between the documents, the change trend of keywords, and cluster analysis of these documents, and finally study the historical citation of the EKC. This article can help researchers who study the curve to provide a direction.

2 Materials and Methods

By searching the topic "Environmental Kuznets Curve" in the Web of Science, selecting publication years from 2010 to 2020, and the database as the Web of Science core collection, 2747 articles were obtained. Export documents, selecting all records in the output section, including Author(s)/Editor(s), Title, Source, Conference Information, Abstract, Cited References, Document Type, Conference Sponsors, Addresses, Times Cited, Keywords, Publisher Information, ISSN / ISBN, Cited Reference Count, Source Abbrev, Page Count, IDS Number, Language, Web of Science Categories, Research Areas, Funding Information, Accession Number, Author Identifiers, Usage Count, PubMed ID, Open Access, Hot Paper, Highly Cited. After pre-processing the literature, the actual publication year of the other 131 articles is 2021, it is found that the actual number of documents published from 2010 to 2020 is 2,616, which are the main parts of the bibliometric analysis of this article.

The 2616 documents were analysed by using the open-source software R language, which is a language and environment for statistical computing. The method is comprehensive scientific measurement analysis, using the bibliometrix package in R. The main analysis is divided into three parts, main information about the collection, analytics and plots for three different level metrics, and analysis of three structures of knowledge and data visualization. There are three analyses, co-citation analysis B_{cocit}, collaboration analysis B_{coll}, co-word analysis B_{coc}.

$$\mathrm{B}_{cocit} = A \times A^{'} \tag{1}$$

A is a document cited reference matrix, $A^{'}$ is the transposed matrix of A, element a_{ij} indicates how many co-citations exist between documents i and j.

$$B_{coll} = B \times B^{'} \tag{2}$$

B is a document author matrix, $B^{'}$ is the transposed matrix of B, element b_{ij} indicates how much collaboration exist between authors i and j.

$$B_{coc} = C \times C^{'} \tag{3}$$

C is a document word matrix, C_{ij} is the transposed matrix of C, element c_{ij} indicates how many co-occurrences exist between words i and j. Figure 1 shows the workflow of this research.

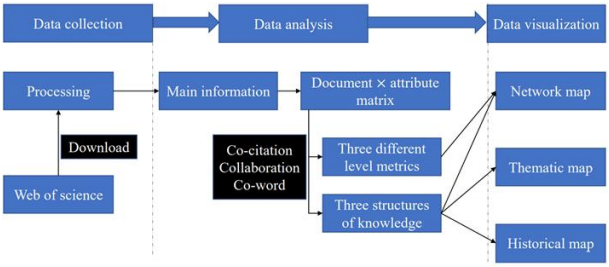

Fig. 1. The bibliometric analysis workflow, which contains data collection, date analysis and data visualization.

3 Results & Discussion

3.1 Main information about the collection

Table 1 shows, the main information of the published papers obtained through statistics of the literature data of the EKC. There are 2,616 articles and 64,946 references for these texts. The data sets of these documents are from 2010 to 2020, there are 389 literature sources and 2,616 articles. And the keywords plus is the calculating keyword by using the author's keywords [19], the author's keywords become the keywords plus from 4887 to 2593. Few articles were completed by a single author, only 312, and most of the articles were completed by multiple people. And co-authors per documents is 3.06.

Table 1. Main information about data

Main information		Document and authors	
Timespan	2010:2020	Keywords plus	2593
Sources (Journals, Books)	389	Author's keywords	4887
Documents	2616	Authors	4334
Average years from publication	3.69	Author appearances	7994
Average citations per document	34.39	Authors of single-authored documents	247

Average citations per year	7.013	Authors of multi-authored documents	4087
References	64946	Single-authored documents	312
Article	2451	Documents per author	0.604
Review	134	Authors per document	1.66
Collaboration index	1.77	Co-Authors per documents	3.06

As shown in Figure 2, according to the graph of article changes over time, it can be seen that the number of articles is increasing every year, with a growth rate of 25.28%, of which there is not much growth from 2010 to 2014, and more growth from 2018 to 2020. From the number of articles changes, it can be seen that the research on the EKC is attracting people's attention greatly in recent years.

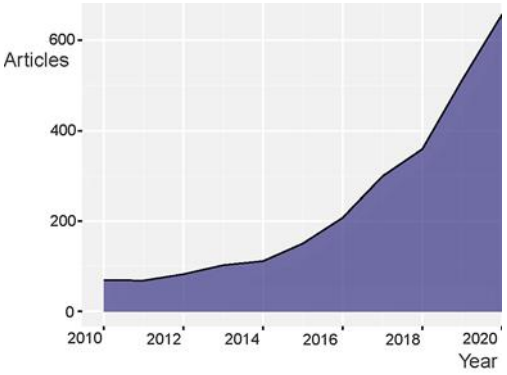

Fig. 2. Annual production of EKC.

3.2 Analytics and plots for three different levels of metrics

The main researches in this part are the three indicators of different levels: the source of the documents, the author, and the documents. According to the sources of these documents and references, we know that Environmental Science and Pollution Research (ESPR) has the most articles, with 375 articles. The second is Journal of Cleaner Production (JCP), with 198 articles. The third is Sustainability, with 150 articles. According to Figure 3, there are five core journals related to EKC research: ESPR, JCP, Sustainability, Renewable and Sustainable Energy Reviews (RSER), and Energy Policy. According to the Brasdord's Law, sources of information on specific subjects [20], these 5 journals provide the articles that accounted for 35.47% of the total number of 2616 articles. There are 64,946 references citing the studied 2616 articles. The most cited journal is Energy Policy. The journals in it have been cited 12,329 times during the studied timespan. Ecological Economics is the second journal, which has been cited 8713 times. The third one is RSER. In the next few years, these documents will become indispensable reference tools and have been cited 7,450 times in the field.

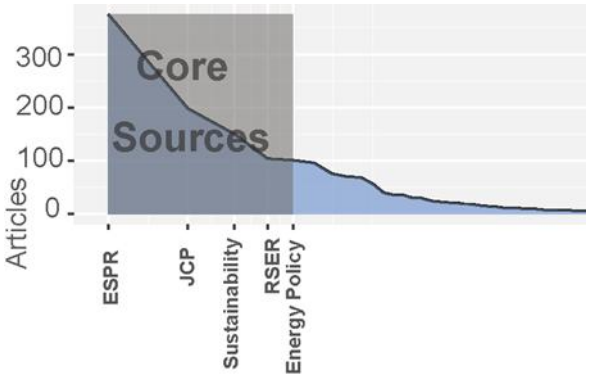

Fig. 3. The picture of Brasdord's Law.

Articles are cited as global citations and local citations. Global citations refer to these references being cited by articles in all fields, and local citations refer to those cited by people in the research field of the EKC, so it is more reasonable and accurate to analyse local citations. Regarding the four indexes cited H, G, total cited (TC), and the number of publications (NP). The index of H is an index to quantify an individual's scientific research output [21]. The G-index is introduced as an improvement of the H-index of Hirsch to measure the global citation performance of a set of articles [22]. Through comparing these source journals, it will be found that the number of publications of ESPR is the most. The G' index of RSER and Energy Policy is 100, but their NP is only 104 and 101. Combining these indexes, it can be concluded that JCP is the most suitable for the EKC.

This part mainly analyses the number of articles by authors, and we can see which authors have studied more on the EKC. It can be concluded that the author with the most articles is SHAHBAZ M, with 66 articles, the second is OZTURK I with 48 articles, and the third is Wang Z with 40 articles. It can also be found that OZTURK I, the most cited research field of the EKC, has been cited 1821 times, followed by SHAHBAZ M with 1707 times, and AL-MULALI U with 792 times. It can be seen from Figure 4 that SHAHBAZ M has been studied the EKC from 2012 to the present, and since 2013, more articles have been published every year. OZTURK I has been researched this issue since 2010. It may be earlier because the record in the Web of Science started in 2010 and published the most articles in 2015. Wang Z also started in 2012. There were no articles from 2013 to 2015 and most articles were published in 2019.

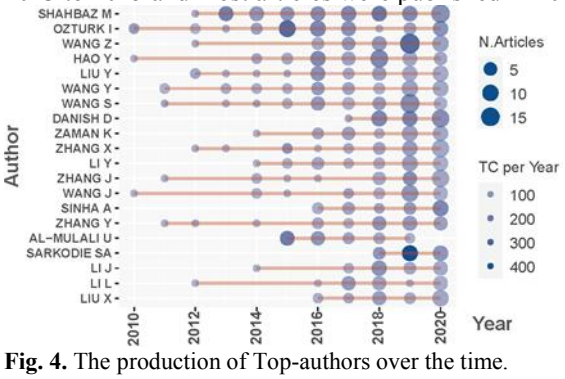

Fig. 4. The production of Top-authors over the time.

School of Management and Economics, Beijing Institute of Technology, and Eastern Mediterranean University, are top three affiliations for publishing which

are 190, 100, and 88, respectively. Figure 5 shows the situation of the countries where the authors of these articles are located, and whether the authors are in a single country or multiple countries. China has the most articles, with 968 articles, and 293 articles in cooperation with other countries, of which the ratio of cooperation between multiple countries is 0.306.

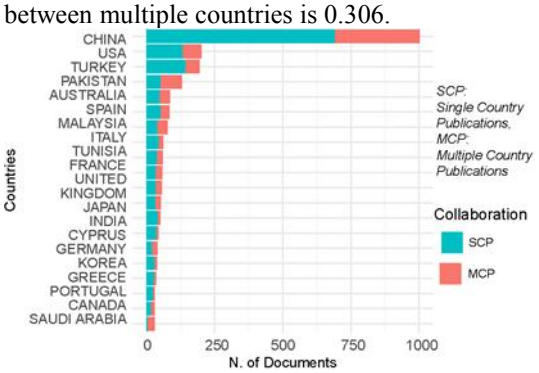

Fig. 5. The country of corresponding author.

After the analysis of the literature, it is mainly the citation of the literature and the change of the keywords. Among the 2616 documents, the most cited is an article named the lancet commission on pollution and health [23], which mainly talks about pollution and health issues, and has little to do with the EKC we are studying. Maybe the problems caused by environmental pollution are closely related to people's health. With the improvement of the economic level, health problems are also important, so it has been cited 1061 times. However, the most cited in this research field, the topic of the EKC, is named testing environmental Kuznets curve hypothesis in Asian countries [8], 230 times, mainly. Among all the references, the most cited is economic growth and the environment [3]. This document belongs to a source of the EKC, so this reference is cited 839 times in the field.

Adding algorithm-derived indexes based on the author's keywords, such keywords can better represent the status of the literature in the bibliometric analysis. After the keywords of these documents are converted by keywords, it can be found through analysis that the EKC appears the most times, with 1220 times, followed by economic growth, and the third is CO_2 emissions. Therefore, the most researched on the EKC is economic growth and carbon dioxide emissions. Through the changes in the subject headings of the literature, in Figure 6, it can be seen that the problem of income balance was studied from 2010 to 2016, 2013 was the focus of Kuznets curves, scenarios, benefits, and the focus of 2018 was economic growth, EKC and Kuznets curve. By 2020, the focus has become on ecological footprint, degradation evidence, and globalization.

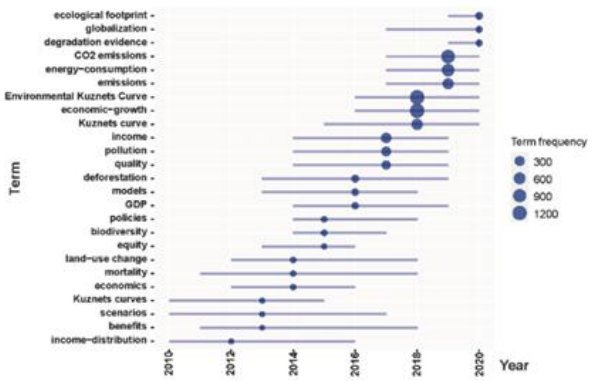

Fig. 6. The trend topic all over the word.

3.3 Analysis of two structures of knowledge

Structures of knowledge are also the science mapping. A general framework for creating a large-scale document space is proposed, as well as some methods of performing certain individual processing steps [24]. It is mainly used for citation data but can be used for other types of documents. The overall picture of scientific knowledge has always been desirable. Scientific mapping attempts to find intellectual connections in the dynamically changing scientific knowledge system and aims to show the structural and dynamic aspects of scientific research [25], and the evolution of theory and technology. After that, each researcher will give a comprehensive overview of the main findings related to his particular field, and scientific mapping allows the investigation of scientific knowledge from a statistical perspective.

3.3.1 Conceptual structure

This part will analyse what science talks about, the main themes, and trends. The conceptual structure represents the relationship between the concepts or words in a set of publications: the words appearing together in the document will be related in the network. It is also called the common word network. This structure is used to understand the topics covered by the research field and to define what is the most important and up-to-date issue also helps to study the evolution over time. Similar to network analysis, the use of clustering algorithms can also be applied to factor analysis. Clustering them can help reduce the dimensionality of elements. By analysing them, the topic network can be drawn, the axis is the centre and density function of the topic network, the time is divided into time slices, and the topic evolution of a specific research field can be represented by the alluvial diagram. When only a small number keywords together of articles were used, they are far away from each other, and larger number articles put keywords together, indicating that they are close to each other.

In factor analysis, the multidimensional scaling method [26] was used, as shown in the Figure 7, the keywords of the article can be seen divided into two categories. When using the clustering method, these keywords are also clustered according to the citations of the article and the keywords used in the article, and up to

9 levels are used. And the keywords of cointegration, tests, error-correction, time-series, and unit-root are the research methods of the EKC, so there are divided into one category. The other category specifically introduces the actual problems of this curve and related influencing factors. These two categories can be simply understood as methodology and practice. Through the clustering and visualization of keywords, the research of these documents can be clearly understood.

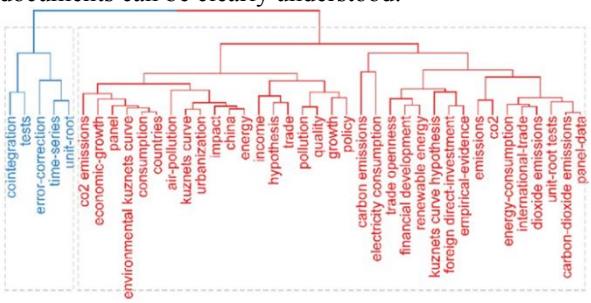

Fig. 7. The topic dendrogram of clustering articles. Blue indicates the method used, red indicates the research question.

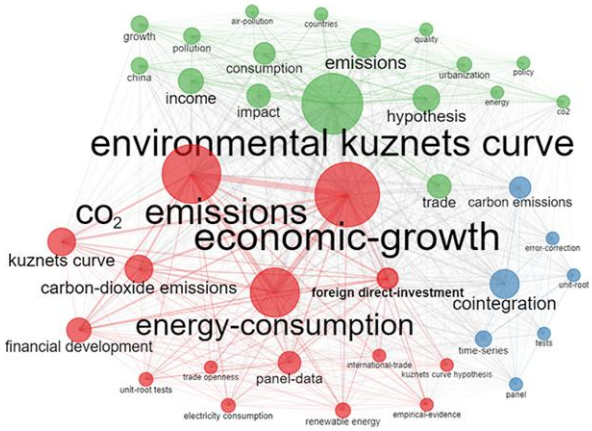

Fig. 8. The Co-occurrence networks of the keywords.

The co-occurrence network analysis of articles by using a clustering algorithm [27] and regularization [28] also is used. Through this co-occurrence network, the mathematical structure between articles can be simulated. The network is composed of lines and points. The vertices represent the keywords of the analysis. The size of the vertices is the number of occurrences. The colours of the vertices are of different types. The lines indicate the connection between them, and the thickness of the line indicates the strength of the connection. As shown in the Figure 8, economic growth and CO_2 emissions fall into one category, and their betweenness is 2.87 and 2.23, in Table 2, cointegration is the second category, and betweenness is 0.42; the EKC is the third category, and betweenness is 2.17. In this classification we can conclude that economic growth, cointegration, and EKC represent the main parts of these three categories. Betweenness for a given node is the number of shortest paths between two nodes. The value of closeness is the mean length of the shortest paths between the node and all other nodes in the network. PageRank for a given node is a metric used to estimate the importance of the node. If the nodes with a higher rank have links to the node, the node has a higher PageRank [29].

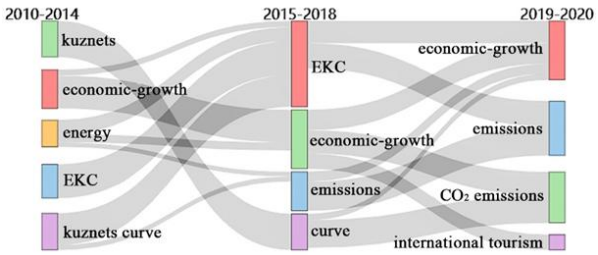

Fig. 9. Thematic evolution and (b) thematic maps.

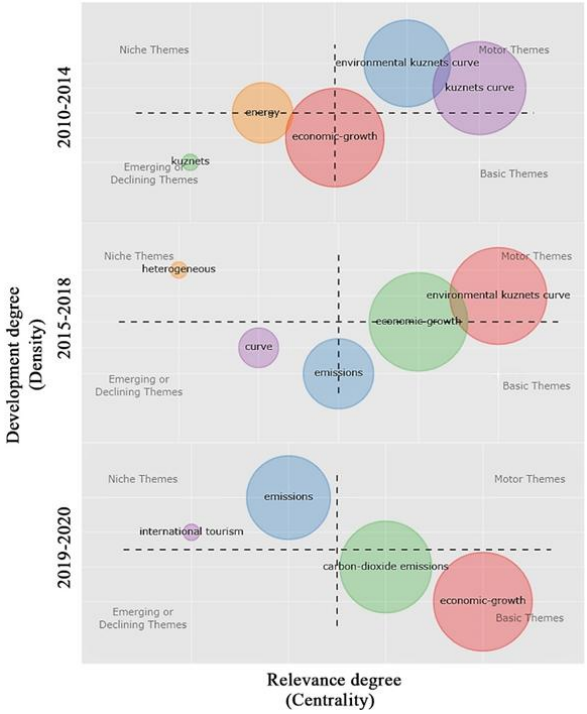

Fig. 10. Thematic maps.

Table 2. The Co-occurrence Network Analysis

Node	Cluster	Betweenness	Closeness	PageRank
Economic-growth	1	2.873	0.0256	0.0795
CO2 emissions	1	2.234	0.0256	0.0721
Energy-consumption	1	1.533	0.0263	0.0588
Cointegration	2	0.425	0.0263	0.0339
Carbon emissions	2	0.220	0.0256	0.0256
Time-series	2	0.162	0.0263	0.0203
Environmental Kuznets Curve	3	2.178	0.0250	0.0716
Emissions	3	0.499	0.0263	0.0333
Hypothesis	3	0.253	0.0263	0.0303

Thematic maps [12] are also used in the analysis. Each cluster can be represented on the map and different colours represent different topics. Callon centrality is represented as the importance of the research field, Callon density is a measure of theme development [30]. According to the number of articles per year, three-time periods from 2010 to 2014, 2015 to 2018, and 2019 to 2020 are selected, as shown in Figure 9. By analysing the changes of the theme maps in different years, we can

further look at the theme evolution of the entire field. In the Figure 6 (b), the upper left part is a highly developed and isolated theme, the upper right part is motor themes, the lower left is an emerging or declining theme, and the lower right part is a basic theme. The study found that the theme of aging in the field of the EKC is cointegration, and the theme of the motor is economic growth. The topic maps of different years and their clusters are shown in the Figure 10.

3.3.2 Intellectual structure

The intellectual structure represents the relationship between the citations of the article. Citation analysis is the most common bibliographic analysis in common citations between authors or documents [11]. Based on the analysis of these citations, the historical trend of the literature was obtained, and a certain historical change map was formed, a new way for the future professional structure was provided [31]. As shown in Figure 11, from the historical direct citation network, the research content of EKC can be found from 2010 to 2020, and the citation rules in it. To study the problem of the EKC, the autoregressive distributed lag (ARDL) bounds testing method was used [32], and the long-term and causal relationship between economic growth, carbon emissions, energy consumption and employment was examined in Turkey [6]. Some studies have questioned the existence of EKC to determine the relationship between environmental quality and economic growth [33]. Because the causal relationship between income and environmental quality cannot be proved, it is necessary to use more representative data and more appropriate statistical techniques [34]. When attracting foreign direct investment, developing countries should strictly review foreign investment qualifications to avoid environmental damage and the management methods of foreign direct investment [35].

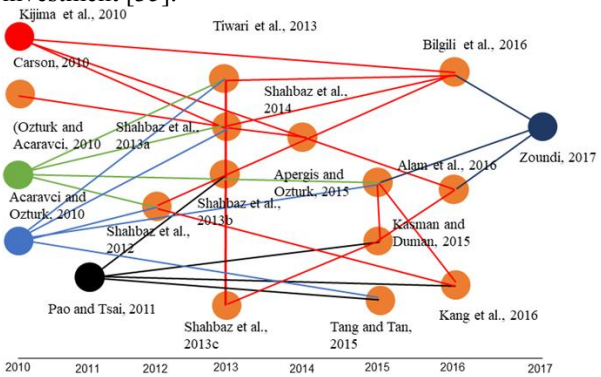

Fig. 11. Historical co-citation network about the EKC.

The research showed that there was a long-term relationship between variables, supporting EKC hypothesizes that energy consumption will increase carbon dioxide emissions [7]. Whether economic development reduces carbon dioxide emissions, the research results verify the link among carbon dioxide emissions, economic development, energy consumption, and economic growth [36]. Indonesia's economic growth, energy consumption, trade openness, and carbon dioxide emissions, and the economic growth and carbon dioxide emissions are also interrelated with a two-way causal relationship [37]. The results of the study confirmed that energy consumption was the main factor causing energy pollutants. Policy and financial development improved the environment and redirect resources to environmentally friendly projects, making a significant contribution to reducing carbon dioxide emissions [38]. The coal consumption and trade openness led to carbon dioxide emissions and trade openness leads to economic growth and coal consumption [39]. By using annual time series data from 1971 to 2010 to investigate the existence of the Tunisian EKC. The results shew that the existence of EKC [40]. The method using panel data was used in a multivariate framework to test the EKC hypothesis [8]. In terms of the inverted U-shaped correlation between emissions and per capita income, the estimated value has expected signs and is statistically significant to provide empirical support for the existence of the EKC hypothesis. At this stage, some technologies can improve energy efficiency, energy conservation, and renewable energy, but low-income countries cannot obtain these technologies due to high costs [41]. The causal relationship between energy consumption, carbon dioxide emissions, economic growth, trade opening, and urbanization was investigated in the new EU states. The estimated coefficients of the lag correction period in the equations of, trade opening is statistically significant [9]. The energy consumption, foreign direct investment, and income are the key determinants of Vietnam's carbon dioxide emissions. It also believes that foreign investment should adopt clean technologies [42]. The annual time series data of India, Indonesia, China, and Brazil were researched during the period 1970-2012 by using the ARDL boundary test method, considering the main linear and non-linear assumptions for short-term and long-term relevant time-series data to carbon dioxide [41]. By applying the spatial panel data model to study China's carbon dioxide EKC hypothesis, the results show that spatial effects affect the shape of the EKC, and the spatial structure of China's provincial carbon dioxide emissions has a clear distribution [43]. All countries should use renewable energy to obtain electricity fairly, and improve renewable energy technologies to increase the supply of renewable energy policies [44]. Research shows that renewable energy has a positive effect on reducing carbon dioxide emissions and is an effective alternative to traditional fossil energy [45].

By analysing the historical map of this curve, it can be found that the problems of environmental pollution and economic development are changing. From 2010 to 2020, the first is simple EKC, followed by carbon dioxide and energy consumption, and sustainable development. It also used different data, different research methods, and studied different pollution. With the development of time, the economy of different places, the pollution of different places, and the spatial impact are also taken into account, so in the end, the EKC problem will be analysed as a whole.

4 Conclusions

The study found that the key issue in EKC is carbon dioxide emissions in environmental pollution, which is resulted from the continuous use of energy. Different countries or cities makes their own local EKC present an inverted U-shape, but destroys the environment of another place. Therefore, when the economic development reaches a certain level and more investment technologies, more renewable energy and clean energy will be used to reduce the overall environmental pollution and reach the real inverted U-shaped EKC. Bibliometric analysis revealed that the NO.1 cited article in the EKC research field is testing EKC hypothesis in Asian countries published by Nicholas Apergisa and Ilhan Ozturkb in 2015, which was published in Ecological Indicators, 230 times. NO.1 cited reference is economic growth and the environment published by Grossman, Gene M and Krueger, Alan BG in NBER WORKING PAPER SERIES in 1995, 839 times. Through the clustering of keywords, the relevant factors of the EKC and the methods to research environmental pollution can be clearly understood. In the following research, more databases should be selected, and all relevant documents should be taken into consideration.

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