Global Perspectives on Environmental Kuznets Curve: A Bibliometric Review

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Abstract: The environmental Kuznets curve (EKC) explains the dynamics associated with income and environmental quality. This study utilizes bibliometric analysis and data visualization techniques and empirically determines the tendencies and patterns in the EKC literature. Furthermore, the study explains intellectual structure, construct development, evolution, collaborations, and research clusters within the EKC research domain during the last two decades, from 2000 to 2020. The study empirically analyzes 2,218 articles and 55,051 references from 328 journals, 4,146 authors, 99 countries, and 50 subject categories. The study used co-citation analysis to examined the noticeable research articles, journals and authors' contribution. Moreover, the co-occurrence analysis examined the prominent countries, institutions and keywords in the concerned literature. Most studies in EKC domain focus on developing regions facing the dual challenge of growth and environmental sustainability. The current initiative categorizes the EKC knowledge domain into major research areas with the help of different clusters namely causality analysis, non-renewable energy, energy consumption, the EKC, and industrial pollution. The study further discusses emerging trends that provide future research fronts and intellectual development within the EKC framework.

Keywords: Environmental Kuznets curve; bibliometrics; carbon emissions; bibliographic coupling

1.   Introduction

The increasing environmental degradation has received considerable attention from academia and mounting public concerns over environmental issues have led to initiatives to mitigate environmental effects globally (Sinha, et al., 2020; Cheng et al., 2021; Qin et al., 2021). Along with other factors, the association between economic development/growth and deteriorating environmental conditions is studied globally at various levels, with different pollutants (Ahmad et al., 2021; Sun et al., 2021). The association between pollution and economic development has attracted considerable attention for a couple of decades. A central discussion in many studies is whether the environmental degradation increases monotonically with economic development. Grossman and Krueger (1991) suggest that economies in the initial developmental stages suffer from declining environmental conditions, with environmental indicators improving in later development stages. This U-shaped relation between economic development and environmental degradation has become known as the environmental Kuznets curve (EKC).

The EKC explains the dynamics associated with income and environmental quality (Kaika and Zervas, 2013; Sinha and Shahbaz, 2018). Polluting emissions and other anthropogenic environmental impacts tend to increase with gross domestic product (GDP) at lower levels of GDP; however, emissions tend to decline after a particular level of per capita GDP, which tends to be different for different pollutants and economies. High incomes favor improved environmental conditions (Alam et al. 2016; Sinha and Bhattacharya, 2016, 2017; Sinha and Sen, 2016). However, the initial studies used simplistic econometric techniques, leading Stern (2017) to conclude that the results from

the early study provided only weak evidence on the EKC. Despite an abundance of studies, there is no final verdict on the existence of the U-shaped relation between economic growth and pollution (Sinha et al., 2017, 2019; Chien et al., 2021). In several developed economies, the emissions of some but not all pollutants have declined.

Different scholars have exhaustively surveyed the literature on the EKC. Dinda (2004) discusses the theoretical and empirical developments on the EKC. He concludes that the literature has not reached a consensus on the income level that provides the turning point from increasing to decreasing pollution levels. Stern (2004) describes the EKC as a fragile economic model vulnerable to econometric misspecifications and little evidence of a common track for the EKC that countries could follow as they achieve high growth. Kijima et al. (2010) summarizes the literature based on the specification of the econometric models used in estimating the EKC. They conclude that the relation between environmental degradation and economic growth must be more complicated than the one implied by a simple quadratic function. Therefore, more sophisticated techniques based on theoretical research should be used. Dasgupta et al. (2002) conclude that the global community must play a key role in lowering and flattening the EKC, with financial support to promote training, policy reforms, data collection, and public awareness on environmental damages rather than aid and trade sanctions, which are inappropriate and ineffective in improving environmental quality.

Stern (2017) indicates that the EKC is statically fragile and shows an increase in environmental pressure with economic growth and a decline as income levels increase. The literature survey of Shahbaz and Sinha (2019) survey also does not find conclusive results on the existence of the EKC, its shape or the location of the turning point. They

emphasize the inclusion of sociopolitical factors in EKC modeling in intra-sectoral, intra-country, and intra-provincial analysis to improve understanding of this dynamic relationship. Sarkodie and Strezov (2019) also confirm the heterogeneity of turning points in the EKC literature. Their most important observation is that the literature so far has expended a lot of effort in studying the EKC for atmospheric indicators of environmental degradation, while ignoring the degradation in other dimensions such as surface water, coasts, biodiversity and land.

The literature surveys as discussed in the previous sections highlight the lack of consensus on the existence of the EKC and modeling issues. However, these survey studies lack the ability to foresee future development of the EKC with its existing intellectual base. Moreover, while growing literature in the multi-disciplinary fashion demands a revisit in the literature to examine EKC's literature growth in the social sphere in the systematic manner. The present study surveys the literature on the EKC from 2000 to 2020 to highlight the dynamics of the linkages between development and environmental changes. This study differs in methods from previous surveys on the EKC because it utilizes bibliometric analysis and data visualization techniques to empirically measure the tendencies and patterns in the EKC literature, to understand institutional and author collaboration, to detect turning point articles within the EKC literature, to comprehend bursts of co-cited references, and to recognize geographic and coherent absorption in the form of clusters in EKC knowledge areas (Budd 1988; Erar 2002; Fairthrone 1969). Bibliometrics technique has been widely adopted statistical method to analyze scientific research work which helps to comprehend and conceptualize the trends in a knowledge domain with its past, present, and future. This technique incorporates citation analysis to develop the citation graph, a network graphs to measure the impact of research article,

keywords linkages and the influence of contributing researchers, universities, and countries., and an association between co-authors. Bibliometric technique is helpful more to conceptualize particular knowledge domain with huge published data. The visualization of knowledge domain gives an opportunity to redirect the research directions for researcher with existing and future constructs contributing in that knowledge domain, indicating evolving trends that can potentially change the EKC construct and become influential. The data visualization and bibliometric techniques help measure the strength of different trends and patterns in the literature, enhancing the scholarly comprehension of cited articles and threading them with the authors' contribution. The bibliometric techniques further help to empirically organize and integrate the available literature in the form of visible clusters, labeling and indicating dominant trends among scholars exploring the EKC knowledge domain (Budd 1988; Erar 2002; Fairthrone 1969).

The bibliometric data analysis techniques also provide visual and empirical presentations of the scholarly work that has constructed new trends in the EKC related literature. Particularly, the adopted bibliometric approach includes the co-citation analysis which helps to underline the turning points (by noticing rapid citation trends), and burst analysis (to highlight the possible paradigm shifts) (C. Chen, 2004). Specifically, bibliometric analysis utilizes the Bradford's dispersion law (Budd 1988), Zipf's law to comprehend EKC knowledge construct intelligently (Piantadosi 2014), and Lotka's law to present noticeable nodes (authors, journals and research articles) (Pao 1985) in the literature. The methods visualize the development quantitatively within EKC knowledge domain with existing intellectual constructs and future development. The remainder of the paper is organized as follows. Section 2 discusses the methods employed to explore the results

empirically. Section 3 presents the bibliometric results of co-citation analysis, burst detection, turning point analysis, author and institutional collaboration, country-level collaboration, and cluster analysis. Section 4 integrates the discussion and the main findings of the study. Finally, Section 5 presents the conclusion and future directions for research.

2.   Empirical methodology

Bibliometrics is a quantitative tool for examining a scientific pool of literature to underline emerging trends, the literature evolution, and exciting turning points and to sketch the growth of specific knowledge areas in the academic sphere (Pritchard 1969). Bibliometrics creates a descriptive view by providing information on publications, citation counts, authors, institutions, journals, and country performance and a relational view by providing information on co-citation and co-word analysis and each academic's intellectual structure and literary discipline.

A bibliometric study helps to conceptualize a knowledge area by creating research fronts and intellectual bases within an academic discipline. In the last couple of decades, the rapid multidisciplinary expansion among academics has contributed significantly in creating new scientific viewpoints of socioeconomic and environmental issues, although most of the studies examine specific problem statements; these specialized research practices deepen intellectual knowledge bases (Swanson 1993, 1989). However, such specialized research practices create weak, less visible, and less narratively explainable multidisciplinary and links that can generate bursts in any discipline's knowledge evolution (Swanson 1993). Bibliometrics is a strategic tool that helps researchers highlight and uncover disciplinary evolution. The present study answers the call for

researchers to focus on vital and untouched possible research fronts by examining the authors, journals, keywords, and research article contributions in the knowledge space (White and McCain 1989).

Bibliometrics analysis includes the application of Bradford's law, which helps to identify the contributions of publishing journals; Lotka's law, which highlights authors' contributions by counting publications and individual productivity; and Zipf's law, which adopts co-word practice to examine keywords and measure their frequency. The present study uses bibliometrics analysis to examine micro- and macrostructural views of topics, corpus expansion, and contributors to the knowledge space. With the help of graph theory and data visualization tools, it maps the network (nodes and links) of authors, journals, and publications in the network view of the EKC's evolution in the academic literature (Narin et al. 1994). Co-citations among research publications, journals, and authors are also examined. Moreover, a clustering method based on co-cited references is adopted that can help create a unique view of works covered in the analysis in the form of intellectual bases, knowledge fronts, and turning points within the knowledge domain (Chen 2004; Chen et al. 2016). Co-word (co-occurrence) analysis is used to determine patterns and trends in keyword evolution over time within the EKC knowledge domain, to understand the expansion and growth of the EKC as a knowledge discipline. This analysis helps to recognize the expansion and development of the EKC as a knowledge discipline uniquely. This study adopts methods previously used in survey studies by Chen et al. (2008, 2012), Chen et al. (2016), and Madani and Weber (2016).

The present study adopts data visualization tools (CiteSpace) to achieve its objectives. CiteSpace is an open access data visualization platform developed in Java that offers the

co-citation–based exploration of authors, journals, and publications. CiteSpace also performs keyword-based co-word (co-occurrence) analysis. For network extraction or cluster views in CiteSpace, minimum spanning tree and pathfinding algorithms help perform the time slicing of the literature's evolution, the labeling of clusters, and the identification of intellectual bases and fronts (Yang et al. 2017). It is adopted to perform author, country, and institutional collaboration analyses.

A complete list of bibliographic records, abstracts, keywords, and citation details is obtained by crawling the Thomson Reuters' Web of Science (WoS). The main purpose of focusing on the Social Sciences Citation Index is to comprehend the development and concerns addressed by the EKC in the social sphere only. The purpose to emphasize specifically the social sphere is to highlight the contribution of researcher in developing the EKC construct with social phenomenon which incorporates economic, environmental and developmental issues. After a pre-analysis is complete and the environment is pre-crawled, a customized search query is adopted to extract data from the WoS core collection. The search query used was TS = (EKC). To keep the results significant and worthy and reduce skew, the nodes with restricted bibliographic details (i.e., conference proceedings, book reviews, and editorial material) excluded from the initial data filtering round. Moreover, the nodes with the self-citation count from the preliminary research excluded to avoid the results' biasness. The publications obtained from WoS for each of the authors was manually revisited to verify the relevance of the search results. A total of 2,218 publications and 55,051 references are included in this study. The data collection was performed in December of 2020 as depicted in fig 1.

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3.   Empirical results

This section reports the findings of the empirical analysis of 2,218 publications and 55,051 references. It also discusses the different analyses (i.e., of co-citations, journals, and institutions), which influence the definition of EKC as a knowledge domain. Article co-citation analysis facilitates the identification of the linkages between researchers and their research in a particular period. This analysis reveals highly influential scholarly work that can reshape the intellectual construct of the EKC as a knowledge domain. The analysis also uses burst detection to facilitate the observation of upcoming research fronts, and it further improves understanding of the construct of any knowledge area by incorporating micro- and macro-level dynamics (Liu et al. 2015).

3.1.   Co-citation analysis

3.1.1. Highly cited articles on the EKC

Analysis of the co-citation of articles discovers the associations among co-cited references. The links between co-cited references are helpful to identify the primary construct of any knowledge domain. In other words, co-citation highlights the count when two nodes cited together in the literature, and provides understanding of the significance of any node (article, author or journal) in the concerned knowledge structure (C. Chen & Paul, 2001). This analysis shows the homogeneity of ideas and references (Chen and Ibekwe-Sanjuan 2010). Highly co-cited articles indicate highly attended ideas and knowledge development in a particular study area. In this analysis, every node represents a single cited article as shown in figure 2.

-------------------------------- **[Add Figure 2 about here]** ------------------------------------

The size of a node indicates the total number of co-citations for a particular research article, and the ring thickness represents the cumulative number of co-citations throughout a specific period (Chen et al. 2012). CiteSpace assigns different colors to nodes and edges to distinguish combined networks, and each year is represented by a different color. The links connecting the nodes denote co-citations among articles, following Seyedghorban et al. (2016), as shown in Fig. 2.

This section presents the ten references with the highest numbers of co-citations, briefly discussing the ideas presented in these EKC studies.

The study by Apergis and Ozturk (2015), "Testing Environmental Kuznets Curve hypothesis in Asian countries," has the highest number of co-citations. This paper examines the EKC hypothesis using panel data for 14 Asian countries from 1990 to 2011. The study introduces the quality of national institutions using four different variables: political stability, government effectiveness, regulation quality, and control of corruption. The study supports the presence of the EKC, where national institutions provide a mechanism for sharing knowledge and diffusion technology for energy efficiency and emission control.

Kasman and Duman's (2015) "CO2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: A panel data analysis" has the second highest number of co-citations and analyzes the EKC hypothesis for European Union (EU) countries from 1992 to 2010 by employing a multivariate framework. The study uses panel regressions and indicates the existence of the EKC. The study shows bidirectional Granger causality between the main variables, which are proven to play an important role in the adjustment process.

The study by Dogan and Turkekul (2016), "CO2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA," is the third most highly ranked co-cited reference, and it tests the EKC along with other causal relationships from 1960 to 2010. The study employs the ARDL bounds testing approach and Granger causality testing. It does not support the presence of the EKC in this case. Energy consumption is the leading cause of carbon emissions, with urbanization responsible for increasing gas emissions. There exists strong Granger causality among the study's variables in both the short and long run.

In fourth place is the study of Al-Mulali et al. (2015), titled "Investigating the environmental Kuznets curve hypothesis in Vietnam." The study uses the ARDL technique and finds no evidence of the EKC. The results indicate a positive and significant relationship between capital and emissions, which is also verified by the effects of imports on emissions, since these mostly comprise industrial machinery, automobiles, plastic, raw materials, and petroleum products.

The fifth most highly co-cited reference is the work of Bilgili et al. (2016), "The dynamic impact of renewable energy consumption on CO2 emissions: A revisited Environmental Kuznets Curve approach." The authors employ panel fully modified ordinary least squares and panel dynamic ordinary least squares estimations for 17 OECD countries from 1977 to 2010. The results support the presence of the EKC for said panel data set. The study emphasizes access to renewable energy technologies and their promotion to combat global warming.

Ozturk and Al-Mulali's (2015) "Investigating the validity of the environmental Kuznets curve hypothesis in Cambodia" is the sixth most highly co-cited reference. The study

employs the generalized method of moments (GMM) and two-stage least squares to examine the EKC by adding governance and corruption into the multivariate framework. The results do not confirm the presence of the EKC when the added variables prove to be significant for environmental quality. The study emphasizes more planned urbanization and industrial waste disposal to improve environmental quality.

Seventh in the co-citation ranks is the work of Lau et al. (2014), "Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: Do foreign direct investment and trade matter?" Their study utilizes a bounds testing approach and Granger causality on a data set from 1970 to 2008. The study confirms the EKC in both the short and long run, with foreign direct investment (FDI) and trade also contributing to environmental degradation. The study emphasizes incentive policies to encourage local industry to adopt green technologies.

"Environmental Kuznets curve for CO2 emissions in China: A spatial panel data approach," by Kang et al. (2016), is the eighth most highly co-cited reference, and it employs a spatial panel data model for the period from 1997 to 2012. The study uses using a spatial panel technique and finds an inverted N-shaped trajectory instead of an inverted U-shaped one. It emphasizes urban agglomeration functions to control emissions.

Tang and Tan's (2015) "The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam" is the second to last in the top ten most highly co-cited references. The study employs a cointegration technique and Granger causality and confirms the presence of the EKC. Energy consumption Granger-

causes carbon dioxide emissions. The study emphasizes clean technologies throughout FDI to promote sustainable economic growth.

The last of the top ten most highly co-cited references is the paper by Alam et al. (2016), titled "Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing Environmental Kuznets Curve hypothesis for Brazil, China, India and Indonesia." The study analyzes the EKC through a multivariate framework. It uses the ARDL bounds test approach and confirms an inverted U-shaped relationship between growth and emissions for all data countries covered except for India, where both variables have positive causal relationships.

3.1.2. Burst detection

CiteSpace facilitates the identification of existing topics and evolving trends in a particular knowledge domain with burst detection. Burst detection categorizes important and potentially new research fronts by identifying articles that have received considerable attention in the study area in a given period (Chen 2006). Statistically, burst observed when unusual attention given to any distinctive node over a definite span of time which helps to drive a new research trend (shift) in the literature (He et al., 2015). Table 1 shows the first five most significant articles, with the strongest citation bursts in the EKC research in the last 20 years. Stern's (2004) "The rise and fall of the Environmental Kuznets Curve" has the strongest burst, followed by Halicioglu's (2009) "An econometric study of CO2 emissions, energy consumption, income and foreign trade in Turkey" and Dinda's (2004) "Environmental Kuznets curve hypothesis: A survey." Fourth is the work of Jayanthakumaran et al. (2012), "CO2 emissions, energy consumption, trade and income: A comparative analysis of China and India," a study that compares the causal

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relationships between growth, trade, energy, and pollutant emissions by using the bounds testing approach to cointegration and the ARDL approach.

Last of the top five is the paper by Arouri et al. (2012), titled "Energy consumption, economic growth and CO2 emissions in Middle East and North African countries," which examines the EKC hypothesis for 12 countries in the Middle East and North Africa, from 1981 2005, by employing bootstrap cointegration techniques. The study confirms the EKC's existence for the countries studied, with various turning points for each country. The results indicate that energy consumption has a significant impact on emissions in the longer term. Finally, references from the journal *Energy Policy* appear the most frequently among the top five in terms of burst detection.

3.1.3. Evolutionary articles

Analysis of co-citations helps identify turning point articles, which are also known as evolutionary articles in the intellectual construct of a study area (Chen 2004). Turning points articles also connect diverse intellectual bases (Chen 2004). In other words, the turning points (pivotal points) refers to the nodes (articles, journals or authors) in the co-citation network which helps to underline the relatedness and connectivity between two of more than two clusters within the concerned knowledge domain (McKerlich et al., 2013). The top evolutionary articles in the EKC knowledge domain are presented below in fig 3.

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The paper by Cole (2004), "Trade, the pollution haven hypothesis and the environmental Kuznets curve: Examining the linkages," scores the highest in terms of turning point

articles. It studies trade flows resulting from a strategy of displacing dirty industries from developed to developing countries, which potentially explains the inverted U-shaped relationship between income and environmental quality. Cole uses detailed trade patterns and their influence on pollution with divergent environmental regulations in the North and South. Net exports as a portion of consumption are measured for four trade pairs from 1977 to 1995.

Ang's (2007) article, titled "Economic development, pollutant emissions, and energy consumption in Malaysia," examines the causal relationship between variables from 1971 to 1999. The study employs a causality test based on an error correction model (ECM) to verify causal linkages. The results indicate that long-run causality between economic growth and energy use, running in the direction from growth to energy. The study finds little evidence of causality between carbon dioxide emissions and economic growth in the long run.

The article by Dinda et al. (2000), "Air quality and economic growth: an empirical study," re-examines the EKC for suspended particulate matter and sulfur dioxide. The study indicates an inverse relationship between environmental degradation and income, which negates the presence of the EKC. Specifically, the study observes an inverse relation for sulfur dioxide and a U-shaped relation for suspended particulate matter, indicating high consumption patterns.

Chang's (2010) "A multivariate causality test of carbon dioxide emissions, energy consumption and economic growth in China" investigates the causal relationship for a multivariate framework. The study employs multivariate cointegration techniques and Granger causality testing. The study covers energy consumption in terms of gas, coal,

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electricity, and crude oil. The results indicate bidirectional causality between economic growth and energy consumption, with causality running in the direction from growth to coal and oil and from electricity to growth. The GDP and energy both contribute to carbon emissions.

3.2. Author co-citation and collaboration

Since 2000, prominent researchers in the EKC knowledge domain with high collaboration frequency include Muhammad Shahbaz, Ilhan Ozturk, Khalid Zaman, Danish, and Usman Al-Mulali. The largest collaboration node is that of Muhammad Shahbaz, which connects to various nodes in the EKC knowledge domain; put differently, the threads from all emerging nodes connect to this node. The second most prominent collaboration according to the bibliometric visualization is that between Ilhan Ozturk, Usman Al-Mulali, and Sakiru Adebola Solarin. Another highlighted collaboration involves the node for Khalid Zaman, which appears to be a separate collaboration cluster and links only to Muhammad Shahbaz. The author collaboration within the EKC knowledge domain is presented in fig 4.

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3.3. Countries and Journals Collaboration

In the bibliometric approach to analysing 'EKC' related literature, the participation by countries can help to construct the macro-level structure of the research field. During the country level co-citation analysis USA ranked first with highest burst, China has second highest burst where Turkey have the third highest burst, the Spain shares the fourth rank and Australia shares the fifth rank in terms of burst as shown in Figure 5. Along with the

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country collaboration bibliometric analysis also help to find the impact of journals within the knowledge domain of EKC. As shown in Figure 6, energy policy, ecological economics, world development, environment economic and management, and environmental science and pollution research appears to be the journal publishing in the knowledge domain of EKC.

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3.4. Cluster analysis

CiteSpace allows for the most critical quantitative function, known as cluster analysis (Chen and Ibekwe-Sanjuan 2010). It categorizes a co-citation network into significant clusters of references closely associated with each other, as well as loosely linked with other clusters (Chen and Ibekwe-Sanjuan 2010). The linkages within a cluster and to other clusters can help identify active research fronts and research areas that need to be attended to more in the EKC knowledge domain. This section presents the top five clusters. Figure 5 shows a cluster analysis visualization. The following discussion highlights the top three references from the five most essential clusters, which can help understand the research direction and construct within the cluster. The cluster evolution is shown in fig 7. The first cluster centers on the use of causality tests.

Causality Analysis Cluster

The article by Aziz et al. (2020), "The role of tourism and renewable energy in testing the environmental Kuznets curve in the BRICS countries: fresh evidence from methods of moments quantile regression," studies the relationships between renewable energy

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consumption, income, tourism, and pollutant emissions in the framework of the EKC hypothesis for the BRICS countries from 1995 to 2018. The authors use panel quantile regression (PQR) for long-run estimation and panel causality tests to examine the causal links between the variables. The PQR results suggest that renewable energy and tourism reduce emissions levels. The EKC hypothesis is also valid for these groups of countries. The causality results indicate bidirectional links between income and carbon emissions and between renewable energy and carbon emissions. However, a one-way link is found from tourism to carbon emissions.

"The relationship between economic growth and carbon emissions in G-7 countries: evidence from time-varying parameters with a long history" by Destek (2020) studies the link between pollutant emissions and income from 1800 to 2010 in G-7 countries. The authors use time-varying cointegration and bootstrap rolling window methods to examine the relationship between the study variables. Their results reveal an inverted M-shaped relationship for the United States, Italy, and Japan. However, this relationship is M shaped for Canada and the United Kingdom, inverted N shaped for Germany, and N shaped for France.

Dogan's (2020) "The use of ecological footprint in estimating the Environmental Kuznets Curve hypothesis for BRICST by considering cross-section dependence and heterogeneity" examines the impact of energy structure, income, and energy intensity on the ecological footprint for BRICST countries. The authors use second-generation methods to estimate the model. Their results indicate that energy structure and energy intensity cause a rise in ecological footprint. The results also show a U-shaped relationship between income and the ecological footprint.

Non-renewable Energy Consumption Cluster

Nathaniel (2020) "Renewable energy, urbanization, and ecological footprint linkage in CIVETS" investigate the association between the ecological footprint and renewable energy. Non-renewable energy, urbanization, trade openness, and urbanization by using the period 1990-2014. The AMG results indicated that income, trade openness, and renewable energy reduce the ecological footprint; however, urbanization and non-renewable energy increase the ecological footprint.

Aziz et al. (2020) "The role of tourism and renewable energy in testing the environmental Kuznets curve in the BRICS countries: fresh evidence from methods of moments quantile regression" studies the relationships between renewable energy consumption, income, tourism, and pollutant emissions in the framework of EKC hypothesis for BRICS for 1995-2018. They used PQR for long-run estimation and Dumitrescu and Hurlin (2012) panel causality test to examine the causal links among the variables. The results suggest that renewable energy and tourism reduce emissions levels. EKC hypothesis was also valid for these groups of countries. The causality results indicated a bidirectional link between income and carbon emissions and renewable energy and carbon emissions. However, a one-way link was found, which was coming from tourism to carbon emissions.

Dogan (2020) "The use of ecological footprint in estimating the Environmental Kuznets Curve hypothesis for BRICST by considering cross-section dependence and heterogeneity" examines the impact of energy structure, income, and energy intensity on the ecological footprint for BRICST countries. They use second-generation methods to estimate the model. Their results indicate that energy structure and energy intensity cause

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increases in the ecological footprint. The results also show a U-shaped relationship between income and the ecological footprint.

Energy Consumption Cluster

Pao and Tsai's (2010) "CO2 emissions, energy consumption and economic growth in BRIC countries" examines the links between output, energy consumption, and polluting emissions. They use BRICS data from 1971 to 2005. The results indicate that energy consumption increases emissions levels. The results also validate the existence of the EKC hypothesis in these groups of countries. They find similar results for the individual country analyses.

The article by Lean and Smyth (2010), "CO2 emissions, electricity consumption and output in ASEAN," studies the associations between emissions, the GDP, and energy consumption for ASEAN countries from 1980 to 2006. The authors use panel methods to estimate the results. The results indicate a positive relationship between energy consumption and emissions, while a nonlinear link is found between the GDP and emissions. The causality results show a one-way link from energy consumption and emissions to the GDP.

Acaravci and Ozturk's (2010) work "On the relationship between energy consumption, CO2 emissions and economic growth in Europe" uses ARDL methods to check the impact of income and energy consumption on emissions for selected European countries under the framework of the EKC hypothesis. Long-run ARDL test results show that energy consumption causes a rise in emissions in all the countries selected. However, the

EKC hypothesis holds for Denmark and Italy. For the remaining countries, income and the square of income were not statistically significantly related to emissions.

EKC Cluster 4:

Stern's (2004) "The rise and fall of the Environmental Kuznets Curve" investigates the EKC literature to explore the statistical analysis on which the EKC is based. Stern discusses the development of theoretical models to generate the EKC, which evolves through appropriate assumptions but little empirical evidence; however, the evidence suggests that the EKC is monotonic. Turning points vary across studies. Studies using purchase power parity have high turning points. A time-related technique effect can effectively reduce emissions, although productivity growth and energy are important, where structural changes and shifts in fuel consumption are less critical quantitatively. Emissions can decline in developed and developing countries, depending on the adoption of innovation in different phases of development. Little evidence exists of a common EKC pathway for countries as their income grows.

Dinda's (2004) "Environmental Kuznets Curve hypothesis: A survey" presents a comprehensive overview and comparison of EKC studies. The income elasticity of environmental quality is more than unity, which denotes it as a luxury good "demanded with high income." The empirical findings suggest the EKC exists for air pollutants, with a direct health impact. No consensus exists for water pollutants, and there is little evidence for other pollutants, such as municipal solid waste. Turning points vary across countries, indicating that all countries do not follow the same EKC path, given political and socioeconomic factors. The EKC tends to hold for the short-term and local pollutants, rather than global and long-term pollutants. Local and country-specific studies are needed

that use decomposition analysis to determine the structural and technological changes associated with the share of the GDP.

Soytas and Sari's (2009) "Energy consumption, economic growth, and carbon emissions: Challenges faced by an EU candidate member" probes the causal links between emissions, gross fixed investment, labor, energy consumption, and income for Turkey. The causality results indicate that carbon emissions Granger-cause energy consumption and there is no causal link between energy use and income and between income and emissions.

Industrial Pollution Cluster

The article of Hettige et al. (2000), "Industrial pollution in economic development: the environmental Kuznets curve revisited," tests the EKC hypothesis from 1989 to 1995 for Brazil, China, Finland, India, Indonesia, Korea, Mexico, the Netherlands, the Philippines, Sri Lanka, Taiwan, Thailand, and the United States. The study focuses on three pollution components: the industrial share of the total output, the sectoral composition, and end-of-pipe pollution intensity, where the EKC is found only for the industrial share component. The study presents optimistic and pessimistic results, where pollution intensity has elastic and unitary elastic relationships, respectively, with economic growth and income. The EKC trajectory is hard to observe without giving weight to other intervening factors.

Gawande's "Internal migration and the environmental Kuznets curve for US hazardous waste sites" tests for the presence of the EKC with the stated variable by separating whites from minority groups. The study is unique because it considers social factors such as migration and population segmentation. It confirms the presence of the EKC, with turning

points found at high income levels. The research indicates migration as a potential source of environmental inequality. Among the social groups studied, whites are more upwardly mobile.

The article by Dinda et al. (2000), "Air quality and economic growth: an empirical study," re-examines the EKC for suspended particulate matter and sulfur dioxide. The study indicates an inverse relationship between environmental degradation and income, negating the presence of the EKC. Specifically, the study observes an inverse relation for sulfur dioxide and a U-shaped relation for suspended particulate matter, indicating high consumption patterns.

--------------------------------- **[Add Figure 7 about here]** -----------------------------------

4.   **Discussion and Future trends**

The present study employs bibliometric and data visualization techniques to quantitatively trace the construct development and evolution of the EKC as a knowledge domain and to offer a critical review for the last two decades. Scientometric techniques are applied to establish a comprehensive overview of the EKC. The current review study is based on empirical results extracted from the above-mentioned techniques and methods, differentiating it from a traditional citation count study. The results show that the domain evolves at the theoretical and methodological levels with the inclusion of socioecological aspects. However, the domination of simple reduced-form modeling with minimal differences in the variables can be detected. Most of the attention is directed at carbon-related emissions, China, tourism, deforestation, and information and communications technology in terms of a causality examination of the environment and

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an income growth nexus, with reduced-form models and a panel cointegration approach. Some of the EKC research fronts have adapted insights from the energy and growth nexus and financial development to investigate the causality links between pollutants, energy, and growth. Most of the studies focus on developing regions facing the dual challenge of growth and environmental sustainability.

---------------------------------- [Add Figure 8 about here] ------------------------------------

The effects of institutions and social/human capital on pollutant emissions and socioeconomic factors to verify the EKC hypothesis has gained less research attention. Most of it has been paid to the turning point of the EKC, where the height of the curve is discussed merely for policymakers to intervene in improving the environment. The co-citation analysis reveals that the articles by Stern (2004), Halicioglu (2009), Dinda (2004), Jalil and Mahmud (2009), and Akbostanci et al. (2009) are the most co-cited, and it proposes the primary intellectual structure discussed above. The above findings are in line with the cluster analysis, which indicates the influence of these research fronts.

The next significant element of this study is the identification of evolutionary articles, which can help trace intellectual transitions. Such transitions denote changes in the EKC models linking the various networks in different time slices. The suggested path based new co-citations has changed, due to the high numbers of publications in the last two years. It starts with Cole (2004), who explores the effects of trade on the EKC. This work is followed by Ang (2007) introducing the linkage of energy and pollutants to economic growth, with Dinda et al. (2000) then examining the EKC with suspended particulate particles and sulfur dioxide, followed by Chang (2010) analyzing the relation between

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emissions, the GDP, and energy consumption by decomposing energy into gas, coal, electricity, and crude oil consumption.

The cluster analysis reveals the major research areas within the EKC domain and indicates carbon dioxide emissions as being actively attended to in the research area. Other studies have incorporated the EKC hypothesis and cross-national analysis. Some have analyzed it through threshold cointegration, while others have focused on natural resources by using multiple frameworks and including variables from environmental pollution and their determinant factors. Almost the same pattern as discussed above arises. The development on the methodological side is impressive, with the inclusion of time series data, decomposition analysis, and social and ecological factors.

Burst detection is helpful in recognizing possible evolutionary articles in the future construct of the EKC. It highlights articles that have ongoing bursts and has the potential to offer new research fronts in the EKC domain. The articles with the strongest bursts, mentioned in Table 1, are those whose bursts were terminated because of increased research attention in the time slice. These articles with ongoing bursts can provide tracks to new research fronts and intellectual development in the EKC with the inclusion of new variables and methodologies to explore the dynamic linkages between environmental quality and economic growth, to help devise policies.

Articles with ongoing bursts in the EKC knowledge area are those by Shahbaz et al. (2014), who examine the causal relationships between among income, energy, and emissions by incorporating trade into a framework to trace evidence of the EKC, and Akbostanci et al. (2009), who explore causality links between economic growth and environmental quality by performing a two-level analysis. The first-level analysis

examines causality between carbon dioxide emissions and income per capita by using time series data, and the second-level analysis utilizes panel data.

Ozturk and Acaravci (2013) investigate the causal relationship between energy and economic growth by implying a multivariate model that includes financial development, trade, economic growth, energy consumption, and carbon emissions. Wang et al. (2011) examine the causal relationships between real output, energy consumption, and carbon dioxide emissions with panel cointegration and a panel vector ECM. Apergis and Ozturk (2015) examine the EKC hypothesis by incorporating institutional quality variables into their framework. They apply a GMM methodology to a multivariate framework to trace evidence of various relationships. Arouri et al. (2012) investigate the relationships between energy, income, and pollutant emissions using panel cointegration and an ECM approach. Chandran and Tang (2013) investigate the EKC along with the causal dynamic relationships between growth, energy, and pollutant emissions by incorporating transportation sector energy consumption and FDI. Fodha and Zaghdoud (2010) study the EKC hypothesis for sulfur dioxide and carbon dioxide by employing cointegration analysis. They find evidence to support the EKC for sulfur dioxide, but they fail to find such a relationship for carbon dioxide, which, instead, appears to be monotonically increasing. Jayanthakumaran et al. (2012) study and compare the causal relationships between growth, trade, energy, and pollutant emissions using a bounds testing approach to cointegration and an ARDL approach. Omri (2013) examines the relationships between carbon dioxide emissions, energy, and growth with GMM methodology and reports bidirectional causality between energy and growth, bidirectional causality between growth and carbon dioxide emissions, and unidirectional causality between energy and carbon dioxide emissions. Saboori and Sulaiman (2013) examine the causality links

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among energy, growth, and emissions and find evidence of the EKC hypothesis using ARDL, a Johansen–Juselius maximum likelihood approach, and a Granger causality test. Shahbaz et al. (2013) analyze the static and dynamic relationships between energy, growth, and emissions with an additional variable for financial development via a bounds testing approach and a Granger causality test.

Keywords that frequently co-occurred from 2000 to 2008 are economic growth, pollution, emissions, the environmental quality, the Kuznets curve, deforestation, population growth, trade, sulfur, spatial autocorrelation, and energy intensity. Keywords that appeared in studies from 2009 to 2013 include democracy, carbon dioxide emissions, regulation, panel data model, energy use, and EKC. The keywords Granger causality, coal consumption, energy consumption, panel data analysis, trade openness, and causality analysis remain prominent from 2014 to 2017. Thus, the intellectual transformation and development of research fronts are confirmed. Ecology remains a highly influential subject category from 2000 to 2010, whereas sociology becomes an influential category from 2007 to 2009. Management, agriculture, and economic policy remain influential subject categories from 2011 to 2013. Civil engineering, water resources, science and technology, green technology, and environmental engineering remain influential subject categories from 2014 to 2017. Which confirms the ongoing burst detected by this study and confirms the construct development in direction of green sustainable technologies to reduce environmental damages. It also identifies the diversification within the knowledge domain which develops with time to handle carbon footprints (Murshed et al., 2021) and material footprints (Razzaq et al., 2021).

5. Conclusion

The EKC knowledge domain has developed substantially since its inception. However, the knowledge domain needs to be improved by integrating more environmental indicators and insights from other disciplines. No consensus exists on the existence, shape, and turning points of the EKC among researchers. The same geographic region can produce opposing arguments on the existence and shape of the EKC, resulting from the data set, the selection of variables, and the choice of methodology. The inclusion of intra-sectoral and intra-country data with the integration of certain sociopolitical indicators (i.e., research and development of alternate energy, export diversity, human capital, education, economic complexity, economic uncertainty, cultural shocks, economic shocks, political shocks, social trust, the corruption index, and political cooperation) would be beneficial for policy recommendations and economic analysis, because they can influence efforts to improve environmental quality. Most importantly the EKC knowledge domain gives few traces where it touches the sustainable development goals SDGs, which can be linked to the findings of the study where researchers are focusing on limited pollutants and data sets.

The study has demonstrated the construct development and trends in EKC knowledge domain but there are some limitations which are necessary to be highlighted to improve the future endeavors with similar techniques and domain. The other citation indexes should be included to have a holistic view of the EKC knowledge domain. The keyword search should be compliment with other terms which have similarity with EKC concept. The results can be cross verified with other visualization techniques which are being used for reviewing different knowledge domains.

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