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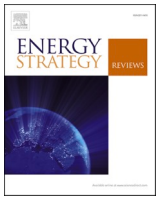

# What have we learned from Environmental Kuznets Curve hypothesis? A citation-based systematic literature review and content analysis

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ABSTRACT

This study provide a bibliometric-based systematic literature review of academic research on the Environmental Kuznets Curve (EKC). The main aim is to identify the leading sources of knowledge in terms of the most influential journals, articles, and authors. Furthermore, a thorough content analysis of the 100 most influential papers is provided for identifying the important research attributes, such as the characteristics of data, methodologies, and major findings. The study identifies 1654 articles on EKC from Scopus-Indexed journals. Ecological Economics is the leading journal based on total citations (15,452), h_index (59), and the g_index (94). The most cited article in terms of total citations belongs to Stern, D. I. entitled "The rise and fall of the EKC curve", published in World Development in 2004. From the content analysis of 100 papers, we find that 66% used panel data. Fully Modified Ordinary Least Square (FMOLS) and Autoregressive Distributed Lag (ARDL) models are the most popular methodologies used in EKC studies so far. CO2 emission is a widely used variable to measure environmental degradation. The majority of the studies have confirmed inverted U-shaped EKC for both panel and time-series studies. The Granger causality results show that income Granger causes environmental degradation. For future direction, it would be interesting to investigate EKC hypotheses against a wider nature-economy nexus that could better explain the sources and causes of change in the type of such nexus. Additionally, adequate and appropriate exogenous variables that could explain external shocks into the nature-economy nexus.

## 1. Introduction

Understanding the complex and intertwined relationship between nature and economy – the *nature-economy nexus* – is of great significance for sustainable economic development. Does today's growth undermine future growth and, as a result of that, the prosperity of future generations? Classical economic doctrines towards this relatively new topic have generally been pessimistic in the long run as it appears in the writings of Adam Smith (1723–1790) and David Ricardo (1772–1823), emphasizing "absolute scarcity" of natural resources such as land for food production. Such pessimism is peaked in Thomas Malthus's writings (1766–1834), now known as Malthusian doctrine. John Stuart Mill (1806–1873) is considered an exception, providing economies with hope to emphasise technological improvements. However, Mill's optimism is shattered by the fascinating notion of the "rebound effect" introduced by William Stanely Jovens (1835–1882). This notion raised significant doubts about the efficacy of technological improvements and efficiency improvements. Since Mill's optimism, mainstream economics had somewhat remained silent on such a fundamental sustainability concern. Nonetheless, since the release of the "Limits to Growth" report of the Club of Rome in the early 1970s [1,2], a neo-Malthusian viewpoint has strongly emerged, refuelling the pessimist viewpoints, undermining the sustainable economic development in the long run. Such a neo-Malthusian view became even more widespread in the aftermath of the oil crises of the 1970s.

Against such a dominant yet silent pessimism in economics, Simon Kuznets' contribution to this topic brought a great deal of optimism. Initially addressing the issue of "equity" or "income inequality" [3,4], it soon found its implications on the areas of "resource depletion" and "pollution" or, generally speaking, on the topic of sustainability of

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economic growth. Kuznets had hypothesised an inverted U-relationship between economic development and income inequality. He had noted that economic inequality was higher in the first stages of industrialisation, but after a certain point, that inequality would begin to decline. However, in the 90s, this classic Kuznets curve theory came to the foreground again. This time it postulated that increasing environmental degradation is a case in the first stages of economic growth. Then after a threshold level is passed in the evolution of economic growth, degradation is reduced. This enrichment of theory became known as the Environmental Kuznets Curve (EKC), coined by Panayotou [5].

The EKC is an empirical hypothesis that confirms the extents to which the sustainability of economic development can be a reality. It is rather a statistical artefact that summarises critical aspects of collective human behaviour in terms of environmental pressures [6] and the sustainability of economic development. Under certain circumstances, it is testing whether or not the depletion of resources and the adverse effects of pollution on the economy might start declining without affecting the per capita income. It assumes that this would happen in highly developed nations. It implies that the intertemporal long-run relationship between per capita income (as a measure of average citizen well-being, shown in the *horizontal axis*) and the magnitude of pollution or resource-use (depicted in the *vertical axis*) will likely be of an ***inverted U shape***. Since the early 1990s, thousands of academic papers have been published to empirically test the likelihood of such an ***inverted U shape*** relationship, hence promising sustainable economic development. Grossman and Kruger [7] have implemented the first empirical research on the EKC. Since then, a bulk of studies have been generated on the EKC, using various variables, covariates and applications in a multitude of different countries. The ***Granger causality*** framework concerns one strand of these studies. However, according to Carson [8]; there is little statistical support for the existence of cointegration relationships in the EKC. Acemoglu and Robinson [9] identify various other reasons for the downward segment of the EKC, such as the political reforms. In this direction, provide their support to other authors too. Lindert [10] refers to the diminishing importance of income generated by land. Williamson [11] refers to the technological change that increases wages faster than the rate of return to capital. Initially, Kuznets and Murphy [12] explain this theory with reference to income inequality and growth, however, later similar concept is applied on environmental impact of economic development. In this context, a comprehensive empirical analysis of EKC is done by Grossman and Krueger [13] and Shafik and Bandyopadhyay [14]. In their analysis, they also proved that the relationship between environment and economic growth varies with respect to resources and policies. Aghion and Bolton [15] suggest that the rich part of the economy pushes down the interest rates and allows the poor to catch up with the rich. Recently, Gokmenoglu et al. [16] examines the EKC hypothesis at the presence of renewable energy consumption, fossil fuel energy consumption, urbanization, and deforestation. Their results show that afforestation grants, tax exemptions for plantations, and tariffs on imports for forest products are crucial to reducing CO2 emissions in host countries. According to Cole and Neumayer [17], additional factors explaining the EKC are the increasing returns to abatement and the pollution havens created from international trade with rich countries exporting their fossil energy operating industries onto lower-income countries.

Concerning the variables employed by researchers to capture environmental degradation, these are of a wide variety. Most studies employ water or air pollution [18–24]. Some studies also employ carbon dioxide, sulphur dioxide, nitrogen oxide, deforestation, biodiversity and various other dimensions of environmental issues that can be regarded as degradation [25–31].

We have identified nine independent *literature surveys* on this topic, summarised in Table 1. Six additional papers have used *meta-analysis* (MAs) based on previous empirical works (see Table 1). Some of these literature surveys have widely received attention among the scholarly community, which is reflected in their *Total Citation* counts (TC) or *Average Per Year* (APY) citations. Stern [32]; with 2859 total citations and 179 average per year citations, is the most highly referenced literature survey on EKC. As aforementioned, six surveys have implemented a meta-analysis. The study by Sarkodie & Strezov [33] has been the most inclusive meta-analysis, including the processed results of 1782 independent articles. This recently published article has already received the highest APY among meta-analyses. All existing literature surveys are of a ***traditional literature review*** (TLR) type. To the best of our knowledge, no ***systematic literature review*** (SLR) of any kind has been undertaken in this field of research.

**Table 1**
Major Literature Review studies and Meta-Analyses on the EKC.

| Ref | Authors | Journal | Number of papers | TC | APY |
|---|---|---|---|---|---|
| **Traditional literature review studies** | | | | | |
| 1 | Stern [32] | World Development | 10 | 2859 | 178.7 |
| 2 | Dinda [6] | Ecological economics | – | 2609 | 163.1 |
| 3 | Shahbaz & Sinha [34] | Journal of Economic Studies | – | 34 | 34.0 |
| 4 | Tiba & Omri [35] | Renewable and Sustainable Energy Reviews | 51 | 97 | 32.3 |
| 5 | Kijima et al. [36] | Journal of Economic Dynamics and Control | – | 314 | 31.4 |
| 6 | Bo [37] | Energy Procedia | – | 101 | 11.2 |
| 7 | Nahman & Antrobus [38] | South African Journal of Economics | – | 75 | 5.0 |
| 8 | Pasten & Figueroa [39] | International Review of Environmental and Resource Economics | – | 39 | 4.9 |
| 9 | Mitić et al. [40] | Economic Analysis | 39 | 0 | 0.0 |
| **Meta-analysis studies** | | | | | |
| 1 | Sarkodie & Strezov [33] | Science of the total environment | 1782 | 37 | 37.0 |
| 2 | Choumert et al. [41] | Ecological Economics | 69 | 82 | 11.7 |
| 3 | Cavlovic et al. [42] | Agricultural and Resource Economics Review | 25 | 185 | 9.3 |
| 4 | Li et al. [43] | Economics Bulletin | 77 | 43 | 3.3 |
| 5 | Koirala et al. [44] | International Journal of Ecological Economics and Statistics | 103 | 17 | 1.9 |
| 6 | Goldman [45] | The Park Place Economist | 77 | 6 | 0.8 |

Notes: TC, total citations, APY, Annual per year citations.

Against the above background, the current paper's main objective is to provide an SLR based on bibliometric data. It also aims to provide a thorough content analysis of academic research articles on the EKC. It pursuits the mapping of literature's evolution, identifying the leading sources of knowledge in the most influential journals, articles, and authors. It will further shed light on the nature of the conceptual knowledge networks on this topic. A thorough content analysis of the 100 most influential papers is also provided concerning research attributes in terms of datasets, methodologies, themes, and major findings. After this introduction (Section 1), the rest of the paper is structured as follows: Section 2 is the methodology section, Section 3 includes the results of the citation analysis, Section 4 includes the results of the content analysis, and Section 5 offers the conclusions.

## 2. Methodology

The methodology in this paper is threefold. It starts with a comprehensive keyword search within the academic database (i.e., Scopus) to collect the relevant documents on the EKC. It is then followed by a citation-based analysis based on bibliometric measures. The analysis is further complemented by the content analysis of the highly ranked articles. This section describes fundamental aspects of the methodologies

used for each of our paper's pursuits, and these are shown in the following sub-sections.

Several academic databases are available to search the relevant papers on the EKC. For instance, these may be SCOPUS, Web of Science, ScienceDirect, ProQuest, Business Sources and many others. Among these databases, the use of SCOPUS and Web of Science is advantageous because they provide detailed bibliometric information for each article, such as TC, APY, references, the funding institution, and the like. Other databases do not provide such detailed data, which is essential to conducting citation-based analyses. In the alternative case that a researcher prefers ScienceDirect, ProQuest and Business Sources, he/she needs to extract bibliometric data from another database that provides them, e.g., Google Scholar, Scopus, or Web of Science in each one of them separately. Understandably this is not time efficient.

Moreover, Google Scholar's citation counts are higher than Scopus figures because Google Scholar also hosts the same publication in all its previous formats (if they have appeared in a public domain even as preprints). Also, the citation counts of Scopus is usually larger than the Web of Science. This is because the list of quality Journals included in each database are different. It is also because citation counts are within their list of journals. For instance, in Google Scholar, almost all journals (high or low quality) are included. Google Scholar's citation counts are counting the published articles and counting working papers, conference proceedings, and alike. This has pros and cons. For instance, Google Scholar may cause issues related to the quality of citation counts, as pointed out in some studies [46,47]. On the contrary, the most rigid citation counts belong to the Web of Science, where only the most quality journals are listed. Scopus is something in between.

Therefore, SCOPUS is a good compromise between the two extremes (Google Scholar with over-counts and Web of Science with under-counts as it excludes many quality journals). Scopus appears to be more accurate than Web of science as documented by some researchers [48–51]. Besides, not every individual/institution has access to the Web of Science database due to its relatively high subscription fee. Many citation analysis and systematic literature studies have used Scopus database and are published in quality journals [52–55].

Thus, this study uses the Scopus database as its search engine for bibliometric data. We started with the following ***Boolean Search String*** of keywords and terminologies that are often used for the EKC literature: ***"Environment Kuznets Curve"*** OR ***Environment Kuznets Curve*** OR ***"EKC hypothesis"***. We specify that the search is done within the ***Title, and Author's Keywords*** of documents. The search results initially generated **1713** documents. We understand that some studies might have used the *Kuznets curve* in some places, and some studies may have used environment/environmental words in other places. Hence, we have combined the above initial search with the following Boolean string***: "Kuznets curve" AND environment*.*** The use of so-called wildcard (*) allows to include both words. As a result, the number of articles increased to 2105 documents. We then noticed that some studies do not use the word ***Kuznets curve*** in either of the titles, and keywords. They use ***environment***, ***growth nexus*** or ***relationship***, instead. Therefore, we added the 3rd stage of search criteria with these expressions that increased the number of articles to **2260**.

We restricted the subject area to environmental science, economics, econometrics, finance, business and management according to subject classification in Scopus. We then decided to limit our documents to published journal articles, books and book chapters by removing conference papers, conference proceedings, editorials and others.[1] This left us with **1841** items. Another 54 non-English documents were removed, leaving a total of 1787 items. At this stage, we manually read the title and abstracts of all remaining articles and found that a total of 145 articles are irrelevant to this topic. Further, to make sure we are not missing any important articles, we manually checked the reference list of the following literature review papers, Selden & Song [56]; Dinda [6]; Stern [32]; Kasman & Duman [57]. As a result of this important exercise 12 missing articles identified and added. Therefore, in the final sample, we are left with **1654** scholarly articles, books and book chapters published during 1992–2022. Fig. 1 visually sketches the samples papers' selection process.

## 3. Results from the citation analysis

This section presents the results from the citation analysis based on 1654 articles published as Scopus indexed journals. More specifically, this section presents analysis on time trend of publications and citations, analysis of journals and analysis of authors and thematic structure (co-words). Additional information about geographical production of EKC papers is in supplementary materials.

### 3.1. Publications and citations trends

Annual scientific production is presented in Fig. 2. This figure reveals that the total number of publications (1992–2022) has been growing more rapidly since 2011. It can be observed that until 2012, the average number of publications per year is 20, but from 2012 and afterwards, it marked an abrupt rise to 120. Several factors might be the reason for this sharp increase. This might be due to the subsequent debate about 'energy and growth' that has motivated researchers to investigate further the relationship between GDP growth and environmental pollution under the EKC framework. For example, early in 2010, scholars may have started focusing more on environmental degradation caused by industrial development or deforestation (for detail, see Refs. [58,59]. A similar trend in the publication number evolution related to energy-growth nexus is also confirmed by Anwar et al. [60] and Ahmad et al. [52–54]. Furthermore, a typical knowledge dissemination platform, such as conference and workshops about energy-growth nexus, has created more awareness among the scientific community globally, maintaining the rising trend.[2] Moreover, the Paris Agreement and the sustainability goals it inspired most signatory countries to follow have also further challenged researchers for additional studies on the various environmental problems and economic sectors and processes that cause them.

To continue the content analysis, Fig. 3 shows the average citations per year for different time intervals. It also identifies the paper which received the highest citations per year given a time frame. The most influential work has been implemented in the first time interval, where the average citations per year are 15.6 per paper. This is basically due to two seminal works by Selden & Song [56] and Stern et al. [61] that have received 47.5 and 47.83 citations per year, respectively. In 2003–2005,

[1] Conference paper, conference reviews and editorials can be included in the sample, however, it has been noticed that these are not necessarily go through a formal peer-reviewed process. Therefore, including them might raise quality issues. Furthermore, conference proceedings – if of high quality – may soon appear as journal articles. Thus, including conference proceedings may result in duplications. Many Systematic Literature Reviews often exclude such publications and are only limited to peered-review journal articles.

[2] For instance, in year 2011, there were two major events (conferences) occurred under the auspices of the World Economic Forum (in Davos) and BONN Conference, both emphasizing on the importance of environment-economy nexus policies, addressing the security of supply of major resources mainly water, food and energy (https://www.weforum.org and http://bonconference.org/).

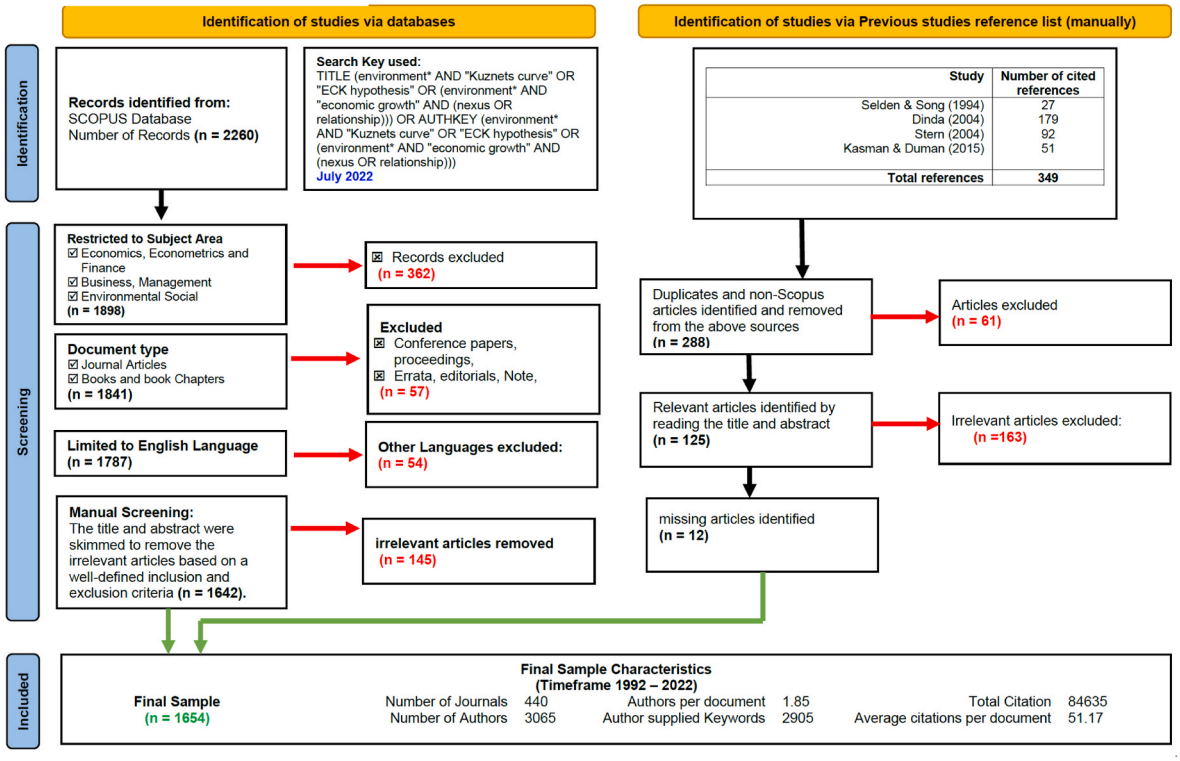



**Fig. 1.** Article selection Flow Chart (PRISMA).

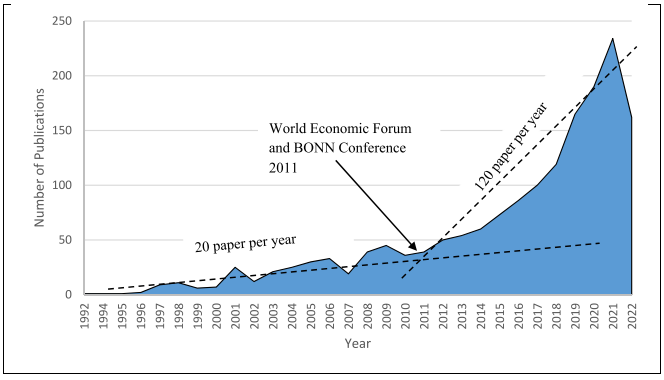



**Fig. 2.** Annual scientific production on EKC (1992–2022).

Stern [32] was the most cited paper, which has received 80 citations per year, whereas the average citations per year per paper in that period was only 5.3. Afterwards and since 2015, Kasman & Duman has remained the most cited paper with 56.6 citations per year in the last five years.

### 3.2. Top publishing outlets for EKC studies

According to the Bradford law developed in 1934, research in any discipline can be divided into different zones with an approximately equal number of papers to identify the core and peripheral journals that publish those papers. The law states that "If scientific journals are ranked in the order of decreasing productivity of articles on a given subject, they may be divided into a nucleus of periodicals more particularly devoted to the subject and several groups or zones containing the same articles as the nucleus" [62]. Fig. 4 depicts the three zones of journals with an approximately equal number of papers and their respective share of total citations. The core zone includes six journals that have published 513 articles, and they have received 45% of the total citations. In Zone 2, there are about 55 journals, the number of published items accounts for 500, and they have received 39% of the total citations.

The papers related to the study of the EKC hypothesis have been published in several journals. However, we have identified the ten most influential journals based on the essential indices, such as the number of publications, total citations, *h_index*,[3] the *g_index*.[4] Fig. 5 reveals that *Ecological Economics* is the leading journal based on total citations, *h_index*, the *g_index*, with scores of 15,452, 59, and 94, respectively. On the other hand, "*Environmental Science and Pollution Research*", with 202 paper titles on EKC, is the top-ranked journal, based on the number of these publications. However, other highly reputed journals, such as the *Energy Policy, Energy Economics, Ecological Indicators, Energy, Journal of Cleaner Production, Environment and Development Economics* and *Sustainability,* have also gained high places in the top journals' list on the publication of EKC studies.

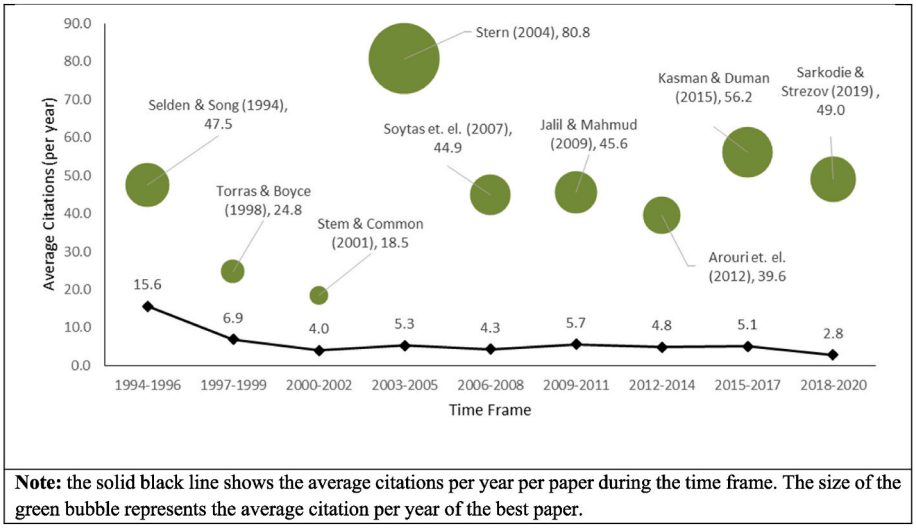
Fig. 6 shows journals growth for the top seven journals in the publication of studies on the EKC. "Environmental science and pollution research" is the fastest growing journal in the field. *Journal of Cleaner Production*, *Sustainability*, *International Journal of Energy Economics and Policy* also show a positive trend. However, *Energy Policy* and *Energy Economics* show a decreasing trend in the publication growth of those papers.

### 3.3. Author analysis

Apart from identifying journals that are the most frequent and cited

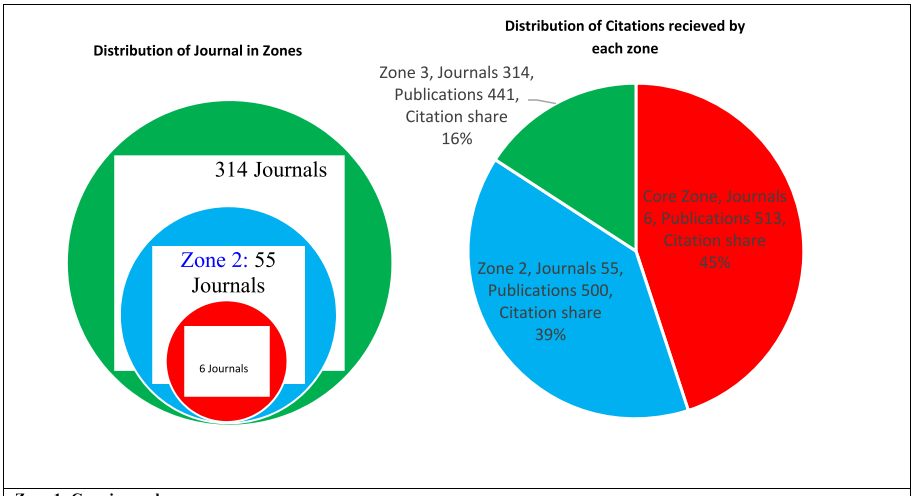
[3] The h-index was introduced by Jorge Hirsch in Hirsch (2005). It is defined as follows: A scientist has index h if h of his/her papers have received at least h citations.

[4] Egghe [162] defined the g-index as "the highest rank such that the top *g* papers have, together, at least $g^2$ citations. This also means that the top $g + 1$ have less than $(g + 1)^2$ papers". The *g-index* is always higher or equal to the h-index.




**Note:** the solid black line shows the average citations per year per paper during the time frame. The size of the green bubble represents the average citation per year of the best paper.

**Fig. 3.** Average citations per year (per paper).




**Zone 1: Core journals**
1. Environmental Science and Pollution Research; 2. Ecological Economics International; 3. Journal of Cleaner Production; 4. Energy Policy; 5. Sustainability (Switzerland); 6. International Journal of energy Economics and Policy

**Fig. 4.** Distribution of journals according to Bradford Law and the citation share of each zone.

publishing outlets for the EKC, it is also evident that only a few well-known scholars have made significant contributions (from the point of view of number and citations) to the literature of the EKC hypothesis testing. Fig. 7 shows the top-10 most relevant and most impacting authors on the EKC study in this context. This is based on the score of the total number of publications and h_index, respectively. According to Fig. 7, Shahbaz, M. is the most productive author in terms of the total number of publications (29). However, Ilhan Ozturk has received 4734 citations with only 20 papers published on this topic. Interestingly, Shahbaz, M. has published many papers in a brief period starting from 2012 to 2022. These findings should be interpreted with some cautions, taking into account the year when a paper is published, reflecting the paper's age and dynamism. For instance, the total citation counts of Ozturk's publication is higher than those for Shahbaz, M. (2421 citations). Foremost, Stern has the 2nd highest total citation counts, i.e. 4,355, but he has been an active author in this field since 1996. Therefore, one should also consider the author's activation year in this research field when comparing one's total citations with others. In sum, we cannot ignore the contribution of these scholars in providing the primary source of knowledge related to the EKC hypothesis testing for its validity.

### 3.4. Thematic structures

In any published paper, the authors must provide some keywords that describe the theme of their study. These keywords contain helpful information about the author's judgment about the research at hand. The careful keyword selection makes their study visible to the future researcher who wants to work on the same topic or theme. Therefore first, we present a word cloud based on the author-supplied keywords. Fig. 8a presents the word cloud based on the authors supplied keywords from the 1654 papers included in our final database. The word which is more frequently used is shown in larger fonts. These keywords are "economic growth", "$CO_2$ emission", and "energy consumption". These three words describe the most important variables used in the empirical framework. Some other common keywords are renewable energy, sustainable development and China. Renewable energy and the environment are a recent addition of words in this literature. Similarly, many studies have now focused on the environmental situation in China. This is also visible from the word growth diagram presented in Fig. 8b.

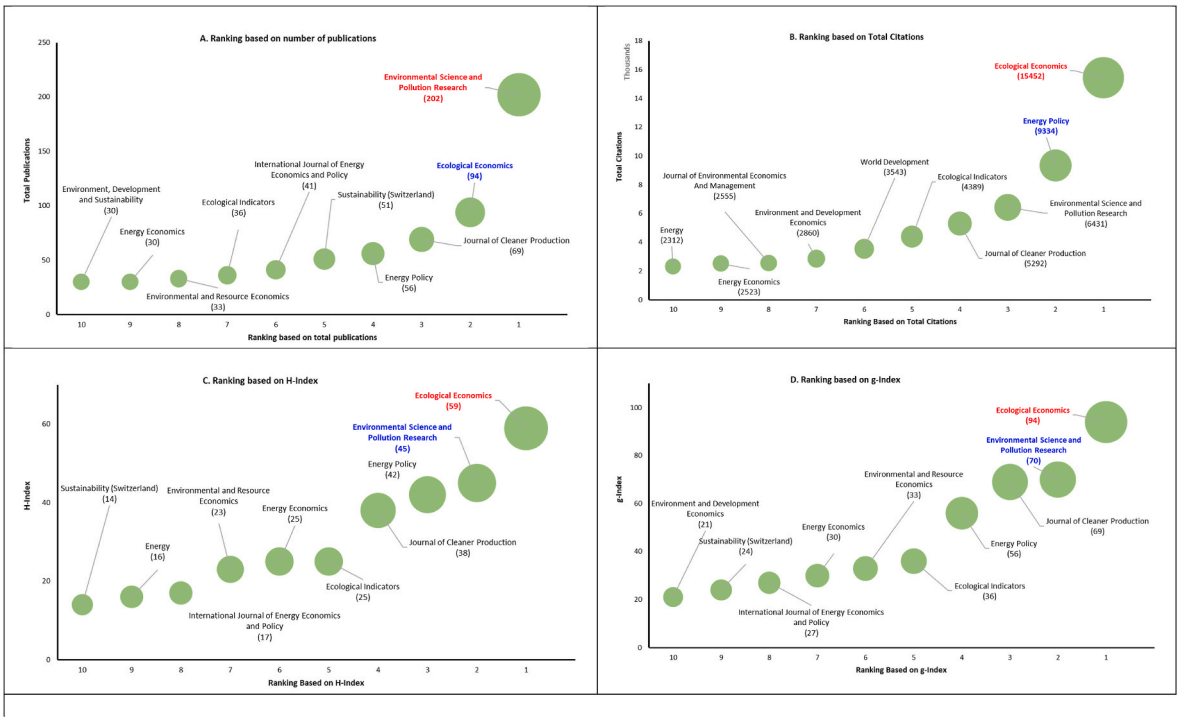



**Fig. 5.** Most influential journals on the study of EKC hypothesis.

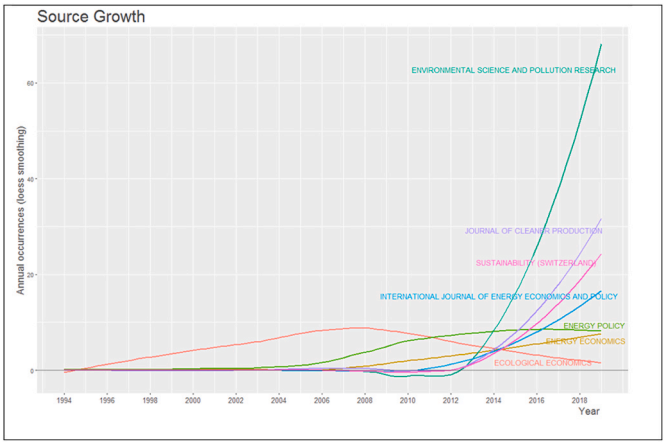



**Fig. 6.** Annual growth of top publication sources.

The thematic structure is about the sets of terms or combinations of words used in a set of publications. This analysis is also called a "co-words network" [63]. This analysis contributes to understanding the main themes investigated in a particular research field, such as the field of the energy-growth nexus or the EKC hypothesis testing. Before showing the co-word analysis results, we show the result of the main keywords used by the author in our database. In this regard, Fig. 9 represents the thematic structure or co-word analysis under the domain of the EKC hypothesis. According to Fig. 9, the most frequently used combinations of terms in this thematic structure are "Environmental Kuznets Curve", "Economic Growth", "Energy consumption", and "CO2 emission". The co-words reveal the framework through which the hypothesis is examined. Thus the usual set-up of these papers evolves around the confirmation of a U-form relationship between the pollution level and the economic growth, and the former is represented by carbon emissions or other greenhouse gases or the reduction of fossil fuel resources and energy consumption which is replaced by energy efficiency and renewable energy sources. This thematic structure also identifies three main clusters represented by the green, red and blue colours.

## 4. Content analysis of the 100 most influential articles

This section analyses the most cited articles within the EKC research topic, ranked by their average citation per year as identified in Section 3. The emphasis would be on the top-100 highest-ranked articles. The prime purpose is to classify and elaborate these papers' vital research dimensions, extracting their fundamental themes. Research dimensions include the type of paper, nature and frequency of data structure and location, variables employed, the methodology used for testing the EKC hypothesis, and the published papers geographical allocation based on authors' country affiliation. The extracted statistics can be employed as meta-data for future studies. In this context, the content analysis aims to identify various routes for further contributions in testing the EKC hypothesis.

Fig. 10 reports the content structure in the top-100 papers. Based on Fig. 10, five articles out of these 100 papers (5%) are literature reviews, and only one of them (1%) is theoretical, while 94 of them (94%) constitute empirical research. Among empirical papers, 61% are panel-data analysis, whereas 31% are time-series analysis, and only 2% are cross-sectional.

### 4.1. Nature of data structure and data location

One of the essential dimensions of empirical studies is to select the appropriate dataset for the intended analysis. In this subsection and the following subsections of Section 4, the literature review and theoretical articles (six papers) are excluded, and only 94 of the sampled studies are considered. Fig. 11 provides information about the data structure, showing the shares of time-series, cross-section and panel-data (across countries or regions over the years) used in the empirical studies. In this figure, the outer circle shows the number of countries in the cross-country panel studies and the region/provinces in a single-country regional or worldwide regional panel-data studies. As can be seen, there only two articles (2%) using cross-sectional data, while 30 items (32%) using the time-series data structure. Thus, there are 62 articles

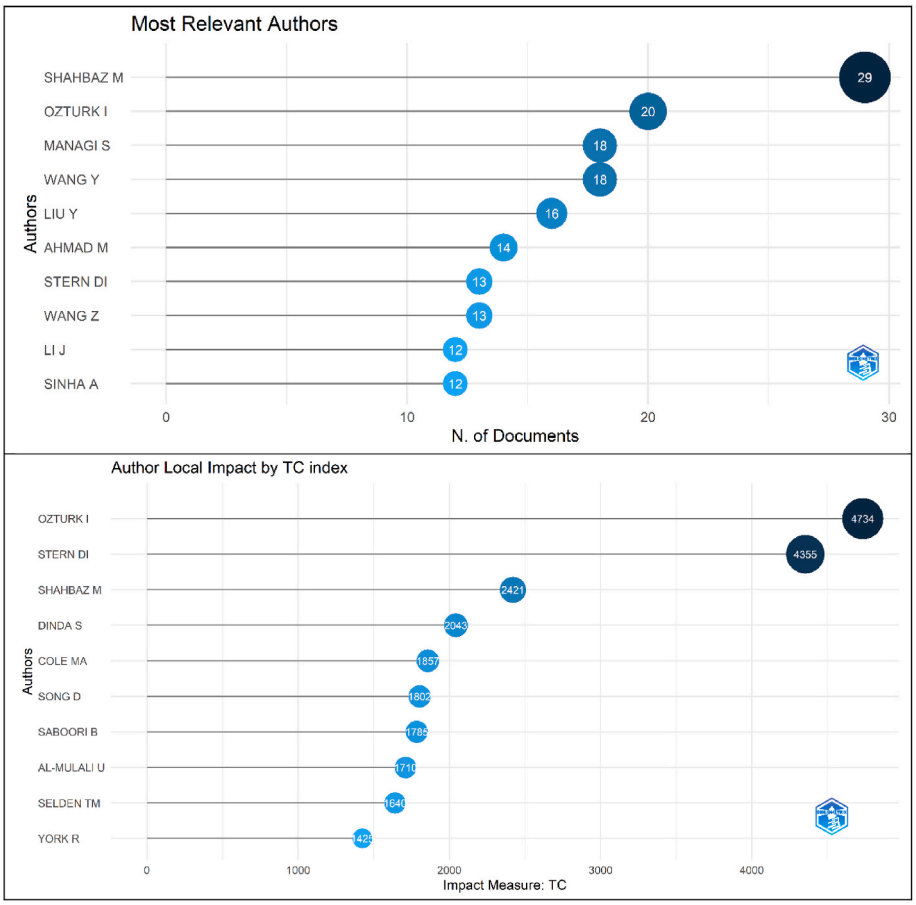



**Fig. 7.** Top influential authors in the study of the EKC hypothesis.

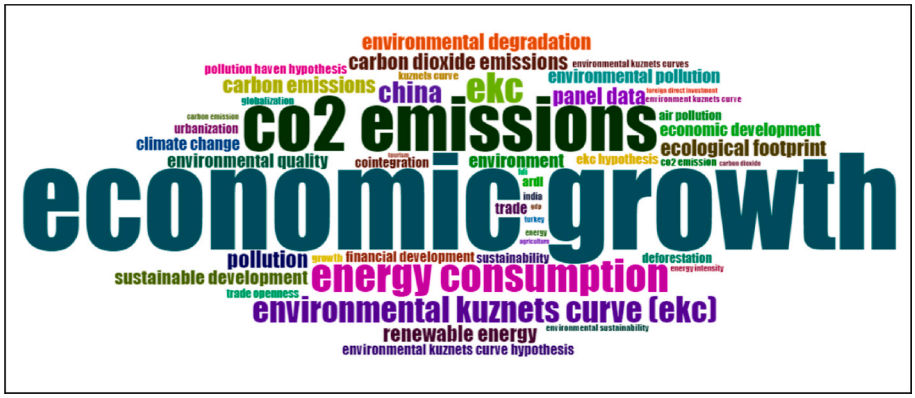



**Fig. 8a.** Word cloud and word growth based on author-supplied keywords.

(66%) that have used panel data. These panel data analyses have been further classified to become more informative.

Out of those above 94 empirical studies, 53% are cross-country panel-data, using two or more countries in their studies. Among them, 20% contain 2-10 countries, 16% contain 11-21countries, 5% comprise 22–31 countries, and 12% consist of more than 31 countries. This shows that the highest percentage belongs to cross-country panel-data studies with less than 21 individual countries. There are also panel-data studies that, instead of being individual cross country studies, are cross-region. These comprise 13% of the sample of empirical studies (12 papers). Among the latter group, 8% of the studies employed more than 30 regions, 4% employed 11 to 30 regions, while only 1% have employed less than ten regions in their panel. Finally, 32% of the sampled studies (30 articles) have performed time-series econometrics with one single country, and 2% (2 papers) have implemented cross-sectional analysis in a specific year.

### 4.2. *The geographical allocation of countries across panel or time-series analyses*

Besides the number of countries in panel and time-series analyses, it is also attractive to learn about where our sampled empirical studies geographical focus is placed. Fig. 12 is for this purpose. It shows which countries or regions have received more attention than others in this literature.

As noted in Fig. 11, on one side, 66% of this sample used panel-data

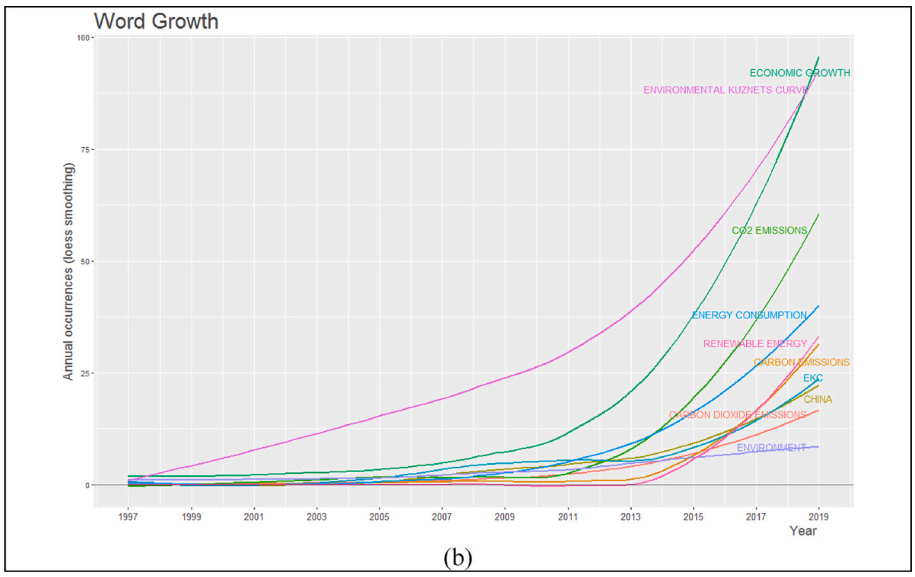



**Fig. 8b.** Word cloud and word growth based on author-supplied keywords.

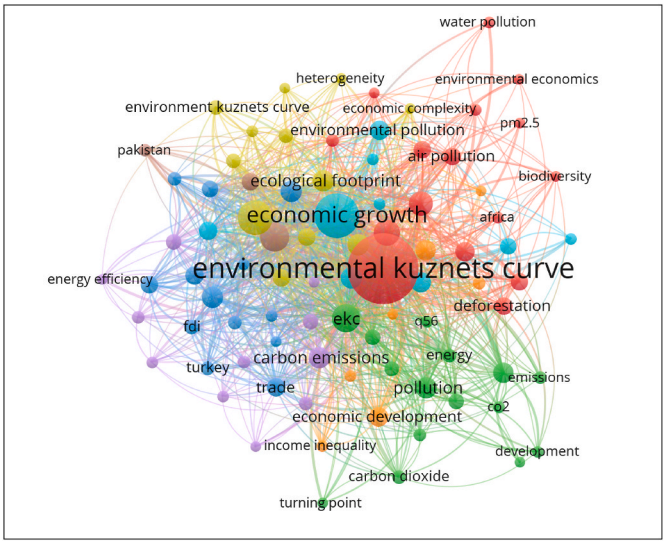



**Fig. 9.** Thematic structure (co-word analysis).

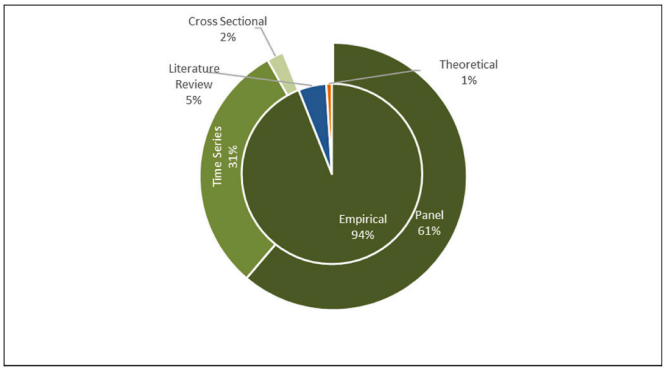



**Fig. 10.** Type of Analyses in EKC-papers within top-100 most cited articles.

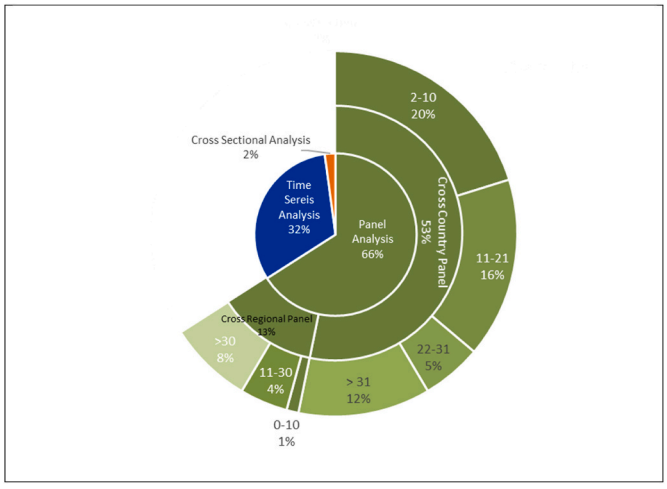



**Fig. 11.** Type of data and number of countries in the analyses.

analysis (62 articles). Among these studies, Fig. 12 shows that 20% covered a wide range of countries from all continents (here, labelled as *Global Sample*), 11% were panels focused on China only (but across *Chinese provinces*). Further, among these panel-data studies, some are focused on well-defined country-groups or regions. For example, 5% deals with the European Union (*EU*), 4% focuses on Brazil, Russia, India, China, and South Africa (*BRICS*) in their analyses. Also, the Association of Southeast Asian Nations (*ASEAN*) and Newly Industrialized Countries (*NICs*) are observed in 3% of this sample. Finally, the Middle East and North Africa (*MENA*), Organization for Economic Co-operation and Development (*OECD*), Developing Countries (*DC*) are each seen in 2% of this sample. In contrast, and other regional panels (*Others*) collectively comprise 14%.

On the other side, 32% of the sample studies have used time-series analysis in a specific country, and 2% have performed cross-session analysis. Fig. 12 shows each study share (as per country) with time-series analysis in descending order: China 6%, India 4%, Malaysia 3%, and Pakistan 3%. Also, Tunisia, the United States, and Vietnam have a 2% share each, while 10% belongs to other individual countries (one paper corresponding to each of these countries). Based on Fig. 12, it is shown that most studies that employed panel-data analysis used a global sample of countries (20%), followed by studies about the Chinese provinces (11%). Furthermore, India and China are the most frequently encountered countries in the EKC investigation's time-series analysis

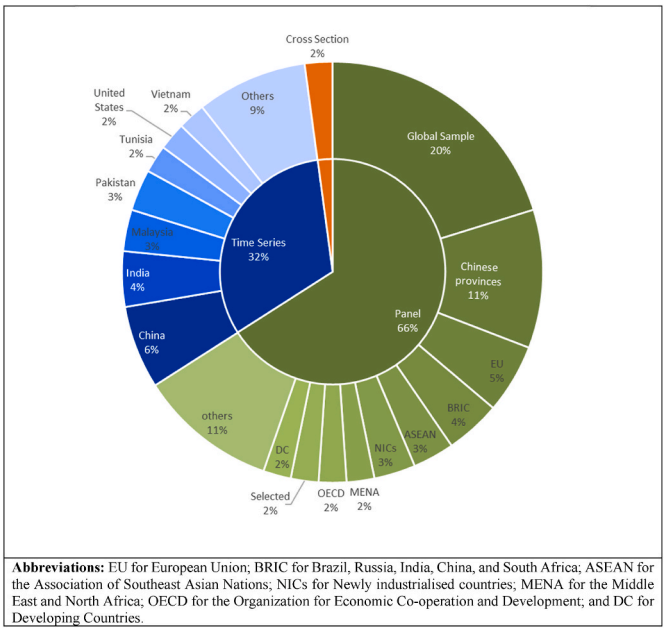



**Fig. 12.** Geographical allocation of countries used in the analysis of the EKC hypothesis.

(together 10%).

### 4.3. The measurement of environmental variables for testing the EKC hypothesis

One of the critical variables that are measured and tested under the EKC hypothesis is the environment. There are two types of variables that are often used in empirical studies. These are either the magnitude of emissions (the mass, e.g., (metric) ***tons, kg,*** and alike) or the concentration rate (the density of particles in a specific volume, often captured by particles per million, ***ppm***).[5] Fig. 13 shows the percentage of studies that used environmental variables. Among the sample studies, 96% used the emissions and only 4% used concentration variables. Fig. 13 also specifies the percentage of a diverse range of emission or concentration indicators used in the sample studies. In emission indicators, mainly atmospheric pollutants are used. Hence, we have not found any indicators for solid waste or water pollutants. It is worth mentioning that while some indicators measure the magnitude of specific substances, e.g., carbon dioxide ($CO_2$), sulphur dioxide ($SO_2$), carbon monoxide (CO) and alike.

Some others studies have captured the accumulation of a class of substances collectively in one year, e.g., greenhouse gases (GHG[6]) or $NO_X$ (Nitrogen Oxide gases, i.e., NO, $NO_2$, $NO_3$). Finally, some studies have employed footprint indicators. This is the measure that indicates the process of emission spillovers over a variety of human activities in a specific year. This has been established as an Ecological footprint (EFP). Based on Fig. 13, most of the sampled articles, i.e., 72%, have used $CO_2$ to measure their EKC analysis emissions. Other indicators are comprised each by less than 10% of the studies. Although CO2 is indeed an essential environmental variable, lack of attention to other measures signals a clear research gap that should be gauged by future studies that will deal with testing the EKC hypothesis.

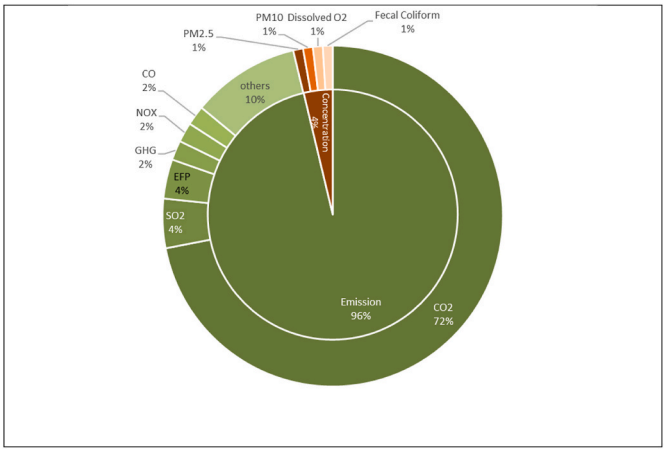



**Fig. 13.** Measurement of Environment Variables in the testing of the EKC hypothesis.

### 4.4. Important control variables in testing the EKC hypothesis

The content analysis has also revealed that some studies have highlighted the importance of two factors as control variables: trade and population. For instance, Antweiler et al. [64]; Cole and Elliott [65] and Kasman and Duman [57] argued that international trade affects consumption and production, which ultimately have a strong influence on environmental pollution. Besides, when the population increases, the demand for goods and energy consumption also increases, affecting the environment and increasing emissions [56,66]. Therefore, both trade openness and population are the critical control variables that have been taken into account while testing the EKC hypothesis.

Fig. 14 shows the percentage of studies that have or have not used these two control variables. For instance, only 3% of the leading studies investigating the EKC hypothesis have used both population and trade as control variables, 21% have used only the trade variable. In comparison, 20% have used the only population as a control variable. Interestingly, a large portion of the sample, i.e. 56%, have used none of these control variables in their empirical analysis, which might create biased results as

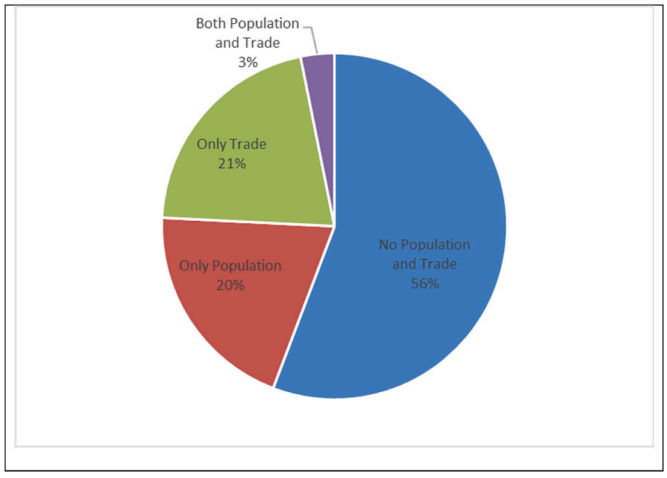



**Fig. 14.** Important control variables, trade and population.

[5] For further explanation on the units of measurment, see EEA agency (2020): https://www.eea.europa.eu.

[6] These gases are mainly *water vapor* ($H_2O$), *carbon dioxide* ($CO_2$), *methane* ($CH_4$), nitrous oxides ($NO_x$), and *ozone* ($O_3$) (see: https://www.c2es.org/content/main-greenhouse-gases/).

highlighted by Antweiler et al. [64]; Cole and Elliott [65] and Kasman and Duman [57].

In the sample used by the current review paper, majority of the studies have used trade and population as control variables. However, few other have used land area, industry share, political stability, violence, quality of public service, terrorism, corruption, urbanization, tropical land, private credit, number of vehicles, and financial development (for detail, see, [67,68]. In this regard, one may argue that trade and population through their comprehensive frameworks would be included in the EKC models. For instance, as the urban population is growing faster than rural, the trade will be driven more by the urban population that boosts mass production and consumption. This group of the population contributes to the increase in environmental pollution. Therefore, such realisations may benefit researchers in carefully selecting those, as mentioned earlier or any other control variables that make sense for a realistic representation of their EKC framework in their future studies.

### 4.5. Methods and empirics under the EKC hypothesis testing

Another essential aspect of the EKC hypothesis testing is the selection of appropriate methods and estimation techniques. An overview of the employed methods may reveal a valuable guide for future contributions in this respect, namely new researchers in the field will be able to observe the deficiencies of the up-to-date methods and employ new methods and perspectives to address issues of the past in an improved way within a more sophisticated framework. Fig. 15 presents the decomposition of estimation techniques identified in the sample of the most influential empirical analyses in the EKC investigation. One should note that this graph's data have been gathered from the 92 empirical studies,[7] but their decomposition sums up to 103 cases. This is because some studies have employed more than one estimation technique in their empirical analysis, and consequently, this counted as two studies. Accordingly, 67% of the sample have applied *panel data*, while 33% have used *time-series* analyses. Among panel studies, 15% have used the *Fully Modified Ordinary Least Square* (FMOLS) approach. The *Generalized Method of Moments* (GMM) and *Panel Vector Error Correction Model* (PVECM) represent 10% of the sample, each. Moreover, *Panel Granger Causality* and *Fixed Effects* methods comprise 8% of the sample each. Finally, 5% of the sampled studies have used *Random Effects*, 4% *Dynamic Ordinary Least Square* (DOLS), 4% *Generalized Least Square* (GLS), and 3% the *Ordinary Least Square* (OLS). In time-series studies, 17% have used the *Auto-Regressive Distributed Lags* (ARDL), 13% a *Vector Error Correction Model* (VECM), and 3% other methods. This implies that the FMOLS and ARDL approaches have been the most dominant estimation techniques used in *panel-data* and *time-series* analyses, respectively.

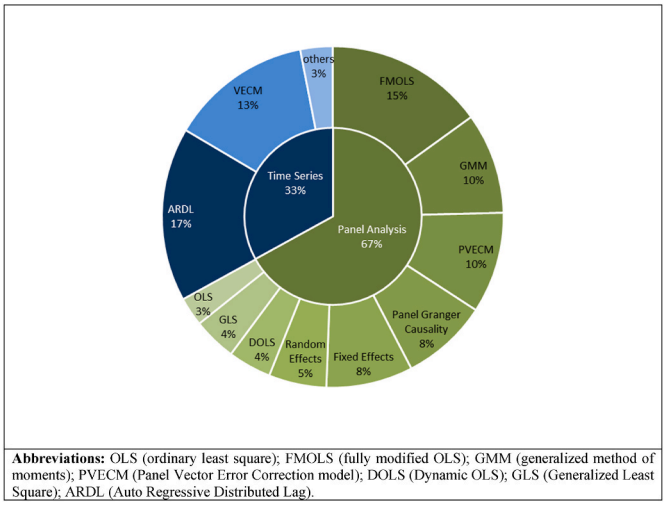



**Fig. 15.** Methodologies used in empirical analysis while testing the EKC hypothesis. **Abbreviations:** OLS (ordinary least square); FMOLS (fully modified OLS); GMM (generalized method of moments); PVECM (Panel Vector Error Correction model); DOLS (Dynamic OLS); GLS (Generalized Least Square); ARDL (Auto Regressive Distributed Lag).

### 4.6. The shape of the EKC

As mentioned in Section 1, the EKC's shape explains the relationship between environmental quality as a dependant variable (e.g., $CO_2$ emission) on the vertical axis and the national well-being as an independent variable on the horizontal axis (often captured by per capita income or GDP). This relationship is often specified, where the independent variables on the right-hand side of the equation appear in a general polynomial form with unknown parameters. After estimating the unknown parameters, the significance and the signs of the parameters will determine the EKC's shape (see, e.g., Ref. [69]. As noted in Section 4.4, apart from environmental and national well-being levels, other variables may also be used in the EKC's specification as exogenous or control variables. Theoretically and according to Simon Kuznets seminal idea [3,4], the EKC's shape is expected to be of an inverted U-type [7,56,70,71]. However, many empirical studies have found alternative EKC shapes, such as the U-shape, *N*-shape, inverted *N*-shape, M-shape, and Q-shape. These shapes, hence, are often shown by iU, U, N, iN, M, and Q, respectively.

Fig. 16 offers detailed information about the percentage of studies that have found different shapes in the EKC relationship.[8] Accordingly, 62% of the 108 studies (those reported the shape of EKC) show that the underlying relationship is of an inverted U-shape (iU), and only 14% confirm the U-shape (U). Furthermore, there is a small percentage of studies that have confirmed other shapes. For example, the inverted *N*-shape (N) by 8%, the M-shape (M) by 4%, the inverted *N*-shape (iN) by 2% and the Q-shape (Q) by 1% of the sampled studies. On the other hand, 9% of the studies do not support these relationships. Overall,

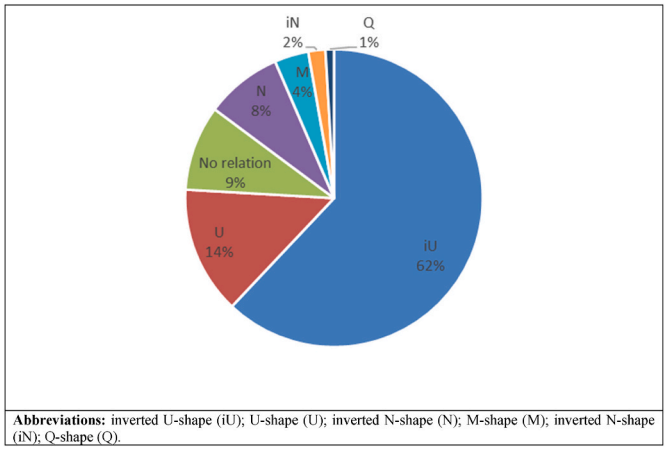



**Fig. 16.** Shape of the EKC. **Abbreviations:** inverted U-shape (iU); U-shape (U); inverted *N*-shape (N); M-shape (M); inverted *N*-shape (iN); Q-shape (Q).

[7] Two *cross-section* studies are excluded from the total 94 emperical studies of the sample.

[8] However, it is also worthwhile to observe for which country and regions, the shape of EKC relationship is different from traditional inverted U-shape. Tables S4 and S5 in the supplementary material offers the detailed information.

content analysis related to the EKC's shape has revealed that most top-ranked studies admit that the inverted U-shape relationship between CO2 emissions and the per capita GDP growth is the most common and applicable shape be confirmed in the literature.

Nevertheless, 38% of the most influential studies do not support the inverted U-shape relationship. This reveals that the EKC's shape is dynamic, and the findings need to continuously updated and further investigated. This is another contribution of our review paper because it can reveal the big picture in this respect.

### 4.7. The turning point of the EKC under an inverted U-shape relationship

Besides the shape of the EKC, the turning point has an important implication in this research field. It explains a certain level of GDP per capita when its effect on CO2 emission becomes negative under an inverted U-shape relationship. Fig. 17 presents the distribution of studies and six income ranges (GDP per capita in US dollars) for the EKC studies' turning points. In total, 41 out of the top 100 studies have reported different income levels as the turning point than the rest of them, grouped into six categories, as shown in Fig. 17. The two highest percentages of these studies are 49% and 27%, with income ranges between 500-5499 and 5500–10499, respectively. This means that 76% of the studies have confirmed that the effect of income on CO2 becomes negative when per capita income reaches a level between 500 and 10,499 USD. The overall average turning point per capita income level across the sample studies is **9260 USD.** On the other hand, only 24% of the studies have reported relatively high per capita income Turing point when the effect of per capita income on CO2 becomes negative. These are pretty exciting results originating from 41 studies that reported the turning points. In this respect, this study provides a direction to future research to further analyse how the turning point level varies across countries or regions.

### 4.8. Granger Causality between GDP and emissions in the EKC studies

Is it GDP that causes emissions to rise, or is it the opposite that is true? Many studies have reported this relationship, which is known as 'Granger Causality' and explores the causal direction between GDP per capita growth (Y) and CO2 emission (C) (for detail, see Refs. [72,73]. In total, 20-panel data and 91 time-series studies (from a sum of 111) have reported the causality relationship under the EKC framework. Fig. 18 presents the percentage share of studies for different causality relationships between Y and C for both panel (in panel a) and time-series studies (in panel b). Regarding panel studies, approximately 40% show that the causality relationship runs from Y to C (i.e., **C ← Y**). In contrast, only 15% confirms that the direction of causality runs from C to Y (i.e., **C → Y)**. At the same time, 30% of the studies is confirmed a two-way causality (feedback hypothesis) between Y and C (i.e., **C ↔ Y)**. Last, 15% of the studies are supported the neutrality hypothesis meaning that no causality exists between C and Y (i.e., **C– Y)**. Concerning time-series studies, the results are not very different from the panel data studies. Here, 45% confirms the causality from Y to C, 7% support causality from C to Y, 30% reveals a two-way causality, while only 15% of the studies confirm the neutrality hypothesis. In sum, we can observe the existence of a dynamic relationship between Y and C, however, still the causality from Y to C is dominant.

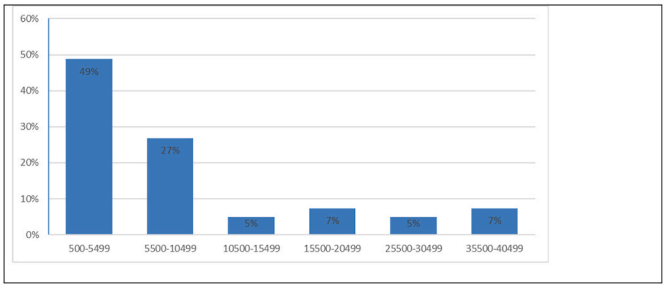



**Fig. 17.** Distribution of the turning point of the EKC.

## 5. Conclusions

This study is a bibliometric-based systematic literature review (SLR) on the Environmental Kuznets Curve (EKC) concept, a consolidated topic in energy and environmental economics. The EKC is originated from Simon Kuznets' contribution to economics in explaining the complex and intertwined relationship between nature and economy. Such a contribution brought about a great deal of optimism against the dominant yet mostly silent pessimism in economics. The empirical works on EKC are vast yet inconclusive. To produce more comprehensive and succinct research in the future, one must have a solid overview of what has happened in the past in this research field. This paper revealed that all existing literature surveys were either built on TLR or MA approaches and lacked in implementing SLR and thorough content analysis. This paper has established the first bibliometric-based SLR of empirical research on the EKC to the best of our knowledge. The contributions of this paper are three folds:

1. This paper explains how complementary could SLRs become compared to the so-called TLR and MA type of literature reviews, which are often arbitrary and not as thorough and reproducible as the bibliometric literature review approach. The most intriguing findings are the following:
   - *Ecological Economics* is the leading journal based on total citations (15,452), h_index (59), the g_index (94).
   - *Environmental Science and Pollution Research* is the most productive journals related to the EKC hypothesis.
   - The most cited article in terms of total citations belongs to Stern, D. I. entitled "The rise and fall of the EKC curve", published in *World Development* in 2004.
   - The most productive author is appeared to be Mohammad Shahbaz, with 29 articles.
   - The top five countries which have become the object of analysis in the investigation of the EKC are China (with 209 studies on it), the USA (with 201 studies), Italy (with 62 countries) and Japan (with 50 studies).
   - China and the USA are the two leading countries, as for as Multiple Country Publication (MCP) and Single Country Publication (SCP) are concerned. Both countries have more than 200 articles.
   - The total number of publications has been growing much faster since 2011 (120 publications per year). This might be due to the subsequent debate about 'energy and growth' motivated by two major events: World Economic Forum and the Bonn Conference.
   - According to Bradford Law [62]; the eight most influential journals are identified in the EKC area. These journals have published one-third of the total publications (513 articles) and received 45% of the total citations.
2. A thorough content analysis of the 100 most influential papers on EKC – ranked by their average citation per year – have also been made in this paper. The main findings of such content analysis include:
   - The majority of the empirical studies have used panel data (i.e., 66%) compared with cross-sectional (2%) and time-series (32%) analyses.
   - Among empirical studies, 96% have used the emissions (measured by the mass), while only 4% used the concentration rate (measured by density) as the environmental degradation variables for testing the EKC hypothesis.
   - The majority of the selected empirical studies have used $CO_2$ to measure emissions (i.e., 72%).

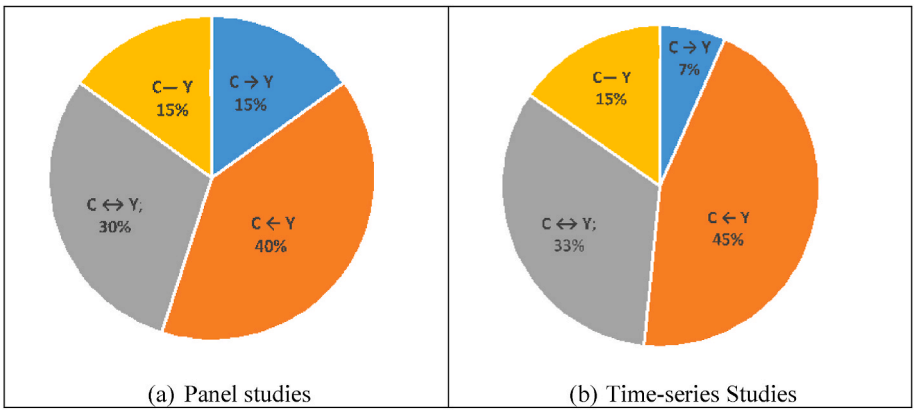



**Fig. 18.** Distribution of Granger Causality results in empirical studies.

- Other studies (i.e., 64%) have used alternative measure for emissions, such as Sulphur dioxide ($SO_2$), carbon monoxide (CO), greenhouse gases (GHG), the class of Nitrogen Oxide gases (i.e., NO, $NO_2$, $NO_3$ collectively labelled as $NO_X$). Ecological Footprint (EFP) comprises 4% of the sample studies.
- Among panel studies, FMOLS is the most useable estimation techniques (15%), followed by GMM (10%) and PVECM (10).
- Among time-series studies, ARDL is the most frequently used technique (17%), followed by VECM (13%).
- Among the studies that have revealed the shape of EKC, 62% identified inverted U-shaped of the curve. In contrast, 29% have found different well-known shapes, such as U-shaped, *N*-shaped, M-shaped, inverted *N*-shaped and Q-shaped. At the same time, 9% are inconclusive about the shape of EKC.
- Among the studies that have found an inverted U-shape relationship, the overall average turning point per capita income level across the sample studies is 9260 USD.
- Overall conservation hypothesis (C ← Y) is the most prevalent result of the Granger Causality test out of empirical studies (panel data and time-series).
- Among the panel studies, 40% confirm the conservation hypothesis, while 30% support the feedback hypothesis (C ↔ Y).
- Among the time-series studies, 45% confirm the conservation hypothesis, while 33% support the feedback hypothesis.

3. The above findings are indispensable for studying the EKC topic and expanding the frontier of human knowledge in this research area. They recapitulated most of all that have been investigated so far, helping to find out the new directions that should be explored in order to promote the solutions to the problems it poses – the *research gaps*. As noted, this review reconfirms that there are many inconclusive or conflicting results in EKC studies. On these ground, we argue that such inconclusiveness is most likely due to the dynamic nature of the nexus between nature and economy throughout development processes, rather than being recognised as a problem. In other words, all shapes of EKC and all four types of Granger causalities between per capita output and environmental degradations may be possible for a country or region under different developmental impediments over time. We would like to highlight previous studies have failed to associate the dynamic change of EKC's shape with institutional changes in cultures, regulations and above-all technologies. Therefore, we suggest that for making a much more succinct contribution to EKC research, one need to implement:
   - much more dynamic testable hypotheses against a wider *nature-economy nexus* that could better explain the sources and causes of change in the type of such nexus
   - adequate and appropriate exogenous variables (far beyond those discussed in Section 4.4) that could explain external shocks into the *nature-economy nexus*

Apart from the above, this paper showed that thorough bibliometric SLRs could address some of the prevalent shortcomings of other literature review approaches (i.e., TLRs and MAs). They should be not regarded as a replacement but rather as complementary to TLRs and MAs. Acknowledging the limitations of the metrics on which any SLR is based upon, many other parameters should be considered when judging a study's quality and influence. Those should not be only its citations. For example, some journals receive more citations because they are open access journals. Some other journals have better pricing and marketing terms for libraries, which guarantees higher visibility for their papers.

Similar considerations should be adopted when one is evaluating the productivity of an author. Some researchers are affiliated with universities that exercise much pressure for the generation of publications, and some other institutions require from their staff a more balanced division of their working time between teaching and research etc. We mean to suggest that we acknowledge all the restrictions placed for authors and journals concerning the citations number, and by no means do we suggest that one journal or author might have more merit than the other. Our review paper aims to guide current and new researchers to the EKC work that has gained more interest and focus by a broad and representative readership. This focus will help them resume and elaborate on what previous researchers have done. By doing so, they can certainly aspire to a wide acknowledgement and collection of citations.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esr.2022.100946.

## Appendix

**Table A1**
List of top 100 papers

| Serial | Reference | Title |
|---|---|---|
| 1 | Sarkodie and Strezov [33] | Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries |
| 2 | Destek and Sarkodie [74] | Investigation of environmental Kuznets curve for ecological footprint: The role of energy and financial development |
| 3 | Bekun, Alola, and Sarkodie [75] | Toward a sustainable environment: Nexus between CO2 emissions, resource rent, renewable and nonrenewable energy in 16-EU countries |
| 4 | Ma and Cai [76] | Do Commercial Building Sector-Derived Carbon Emissions Decouple from The Economic Growth in Tertiary Industry? A Case Study of Four Municipalities in China |
| 5 | Sharif, Raza, Ozturk, and Afshan [77] | The dynamic relationship of renewable and nonrenewable energy consumption with carbon emission:A global study with the application of heterogeneous panel estimations |
| 6 | Chen, Wang, and Zhong [78] | CO2 emissions, economic growth, renewable and non-renewable energy production and foreign trade in China |
| 7 | Hassan, Xia, Khan, and Shah [79] | Economic growth, natural resources, and ecological footprints: evidence from Pakistan |
| 8 | Balsalobre-Lorente, Shahbaz, Roubaud, and Farhani [80] | How Economic Growth, Renewable Electricity and Natural Resources Contribute to Co2 Emissions? |
| 9 | Ulucak and Bilgili [81] | A reinvestigation of EKC model by ecological footprint measurement for high, middle and low income countries |
| 10 | Pata [82] | Renewable energy consumption, urbanization, financial development, income and CO2 emissions in Turkey: Testing EKC hypothesis with structural breaks |
| 11 | Sinha and Shahbaz [83] | Estimation of Environmental Kuznets Curve for CO2 emission: Role of renewable energy generation in India |
| 12 | Danish, Zhang, Wang, and Wang [84] | Role of renewable energy and non-renewable energy consumption on EKC: Evidence from Pakistan |
| 13 | Z. X. Wang and Ye [85] | Forecasting Chinese carbon emissions from fossil energy consumption using non-linear grey multivariable models |
| 14 | He, Xu, Shen, Long, and Chen [86] | Impact of urbanization on energy related CO2 emission at different development levels: Regional difference in China based on panel estimation |
| 15 | Y. Wang et al. [87] | A disaggregated analysis of the environmental Kuznets curve for industrial CO2 emissions in China |
| 16 | Najid Ahmad et al. [88] | Modelling the CO2 emissions and economic growth in Croatia: is there any environmental Kuznets curve? |
| 17 | Dong, Sun, and Hochman [89] | Do natural gas and renewable energy consumption lead to less CO2 emission? Empirical evidence from a panel of BRICS countries |
| 18 | Paramati, Alam, and Chen [90] | The Effects of Tourism on Economic Growth and CO2 Emissions: A Comparison between Developed and Developing Economies |
| 19 | Shahbaz, Nasreen, Ahmed, and Hammoudeh [91] | Trade openness–carbon emissions nexus: the importance of turning points of trade openness for country panels |
| 20 | Jebli, Youssef, and Ozturk [92] | Testing environmental Kuznets curve hypothesis: The role of renewable and non-renewable energy consumption and trade in OECD countries |
| 21 | Dogan and Turkekul [93] | CO2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA |
| 22 | S. Wang, Li, Fang, and Zhou [94] | The relationship between economic growth, energy consumption, and CO2 emissions: Empirical evidence from China |
| 23 | Hao and Liu [95] | The influential factors of urban PM2.5 concentrations in China: A spatial econometric analysis |
| 24 | Dogan and Seker [96] | Determinants of CO2 emissions in the European Union: The role of renewable and non-renewable energy |
| 25 | Alam, Murad, Noman, and Ozturk [97] | Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing Environmental Kuznets Curve hypothesis for Brazil, China, India and Indonesia |
| 26 | Kang, Zhao, and Yang [98] | Environmental Kuznets curve for CO2 emissions in China: A spatial panel data approach |
| 27 | Li, Wang, and Zhao [99] | Environmental Kuznets Curve in China: New evidence from dynamic panel analysis |
| 28 | Apergis [100] | Environmental Kuznets curves: New evidence on both panel and country-level CO2 emissions |
| 29 | Ertugrul, Cetin, Seker, and Dogan [101] | The impact of trade openness on global carbon dioxide emissions: Evidence from the top ten emitters among developing countries |
| 30 | Zaman, Shahbaz, Loganathan, and Raza [102] | Tourism development, energy consumption and Environmental Kuznets Curve: Trivariate analysis in the panel of developed and developing countries |
| 31 | A. Ahmad et al. [103] | Carbon emissions, energy consumption and economic growth: An aggregate and disaggregate analysis of the Indian economy |
| 32 | Al-Mulali, Solarin, and Ozturk [104] | Investigating the presence of the environmental Kuznets curve (EKC) hypothesis in Kenya: an autoregressive distributed lag (ARDL) approach |
| 33 | Kasman and Duman [57] | CO2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: A panel data analysis |
| 34 | Apergis and Ozturk [105] | Testing environmental Kuznets curve hypothesis in Asian countries |
| 35 | Al-Mulali, Saboori, and Ozturk [106] | Investigating the environmental Kuznets curve hypothesis in Vietnam |
| 36 | Tang and Tan [107] | The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam |
| 37 | Farhani and Ozturk [108] | Causal relationship between CO2 emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia |
| 38 | Al-Mulali, Weng-Wai, Sheau-Ting, and Mohammed [109] | Investigating the environmental Kuznets curve (EKC) hypothesis by utilizing the ecological footprint as an indicator of environmental degradation |
| 39 | Omri, Daly, Rault, and Chaibi [110] | Financial development, environmental quality, trade and economic growth: What causes what in MENA countries |
| 40 | Heidari, Turan Katircioğ; lu, and Saeidpour [111] | Economic growth, CO2 emissions, and energy consumption in the five ASEAN countries |
| 41 | Yin, Zheng, and Chen [112] | The effects of environmental regulation and technical progress on CO2 Kuznets curve: An evidence from China |
| 42 | Ozturk and Al-Mulali [113] | Investigating the validity of the environmental Kuznets curve hypothesis in Cambodia |
| 43 | Shahbaz, Nasreen, Abbas, and Anis [114] | Does foreign direct investment impede environmental quality in high-, middle-, and low-income countries? |
| 44 | Liu, Zhou, and Wu [115] | Assessing the impact of population, income and technology on energy consumption and industrial pollutant emissions in China |
| 45 | Shafiei and Salim [116] | Non-renewable and renewable energy consumption and CO2 emissions in OECD countries: A comparative analysis |
| 46 | Lau, Choong, and Eng [117] | Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: do foreign direct investment and trade matter? |
| 47 | K. Wang and Wei [118] | China's regional industrial energy efficiency and carbon emissions abatement costs |
| 48 | S. Wang, Fang, Guan, Pang, and Ma [119] | Urbanisation, energy consumption, and carbon dioxide emissions in China: A panel data analysis of China's provinces |
| 49 | S. Wang, Ma, and Zhao [120] | Exploring the relationship between urbanization and the eco-environment - A case study of Beijing-Tianjin-Hebei region |
| 50 | Kivyiro and Arminen [121] | Carbon dioxide emissions, energy consumption, economic growth, and foreign direct investment: Causality analysis for Sub-Saharan Africa |

(*continued on next page*)

**Table A1** (*continued*)

| Serial | Reference | Title |
|---|---|---|
| 51 | Shahbaz, Sbia, Hamdi, and Ozturk [122] | Economic growth, electricity consumption, urbanization and environmental degradation relationship in United Arab Emirates |
| 52 | Boutabba [123] | The impact of financial development, income, energy and trade on carbon emissions: Evidence from the Indian economy |
| 53 | Salahuddin and Gow [124] | Economic growth, energy consumption and CO2 emissions in Gulf cooperation council countries |
| 54 | Onafowora and Owoye [125] | Bounds testing approach to analysis of the environment Kuznets curve hypothesis |
| 55 | Bölük and Mert [126] | Fossil & renewable energy consumption, GHGs (greenhouse gases) and economic growth: Evidence from a panel of EU (European Union) countries |
| 56 | Omri [68] | CO2 emissions, energy consumption and economic growth nexus in MENA countries: Evidence from simultaneous equations models |
| 57 | Saboori and Sulaiman [127] | Environmental degradation, economic growth and energy consumption: Evidence of the environmental Kuznets curve in Malaysia |
| 58 | Kaika and Zervas [69] | The Environmental Kuznets Curve (EKC) theory—Part A: Concept, causes and the CO2 emissions case |
| 59 | Ozcan [128] | The nexus between carbon emissions, energy consumption and economic growth in Middle East countries: A panel data analysis |
| 60 | Shahbaz, Kumar Tiwari, and Nasir [129] | The effects of financial development, economic growth, coal consumption and trade openness on CO2 emissions in South Africa |
| 61 | Saboori and Sulaiman [130] | CO2 emissions, energy consumption and economic growth in association of Southeast Asian Nations (ASEAN) countries: Acointegration approach |
| 62 | Arouri, Ben Youssef, M'Henni, and Rault Youssef, M'Henni, and Rault [131] | Energy consumption, economic growth and CO 2 emissions in Middle East and North African countries |
| 63 | Saboori, Sulaiman, and Mohd [22] | Economic growth and CO 2 emissions in Malaysia: A cointegration analysis of the Environmental Kuznets Curve |
| 64 | [132] | CO 2 emissions, energy consumption, trade and income: A comparative analysis of China and India |
| 65 | Z. Wang, Yin, Zhang, and Zhang [133] | An empirical research on the influencing factors of regional CO2 emissions: Evidence from Beijing city, China |
| 66 | Hamit-Haggar [134] | Greenhouse gas emissions, energy consumption and economic growth: A panel cointegration analysis from Canadian industrial sector perspective |
| 67 | H. T. Pao, Fu, and Tseng [135] | Forecasting of CO2 emissions, energy consumption and economic growth in China using an improved grey model |
| 68 | H. T. Pao and Tsai [136] | Multivariate Granger causality between CO2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): Evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries |
| 69 | Sharif Hossain [137] | Panel estimation for CO2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries |
| 70 | Jalil and Feridun [138] | The impact of growth, energy and financial development on the environment in China: A cointegration analysis |
| 71 | H. T. Pao and Tsai [139] | Modeling and forecasting the CO2 emissions, energy consumption, and economic growth in Brazil |
| 72 | Nasir and Ur Rehman [140] | Environmental Kuznets Curve for carbon emissions in Pakistan: An empirical investigation |
| 73 | Jaunky [141] | The CO2 emissions-income nexus: Evidence from rich countries |
| 74 | Acaravci and Ozturk [142] | On the relationship between energy consumption, CO2 emissions and economic growth in Europe |
| 75 | Narayan and Narayan [143] | Carbon dioxide emissions and economic growth: Panel data evidence from developing countries |
| 76 | H.-T. Pao and Tsai [144] | CO2 emissions, energy consumption and economic growth in BRIC countries |
| 77 | Lean and Smyth [145] | CO2 emissions, electricity consumption and output in ASEAN |
| 78 | Fodha and Zaghdoud [24] | Economic growth and pollutant emissions in Tunisia: An empirical analysis of the environmental Kuznets curve |
| 79 | Apergis, Payne, Menyah, and Wolde-Rufael [146] | On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth |
| 80 | Apergis and Payne [147] | The emissions, energy consumption, and growth nexus: Evidence from the commonwealth of independent states |
| 81 | Artur Tamazian and Rao [148] | Do economic, financial and institutional developments matter for environmental degradation? Evidence from transitional economies |
| 82 | Ghosh [149] | Examining carbon emissions economic growth nexus for India: A multivariate cointegration approach |
| 83 | Jalil and Mahmud [150] | Environment Kuznets curve for CO2 emissions: A cointegration analysis for China |
| 84 | Apergis and Payne [151] | CO2 emissions, energy usage, and output in Central America |
| 85 | Akbostancı, Türüt-Aşık, and Tunç [30] | The relationship between income and environment in Turkey: is there an environmental Kuznets curve? |
| 86 | A. Tamazian, Chousa, and Vadlamannati [152] | Does higher economic and financial development lead to environmental degradation: Evidence from BRIC countries |
| 87 | Carson [58] | The environmental Kuznets curve: Seeking empirical regularity and theoretical structure |
| 88 | Huang, Hwang, and Yang [153] | Causal relationship between energy consumption and GDP growth revisited: A dynamic panel data approach |
| 89 | Auffhammer and Carson [154] | Forecasting the path of China's CO2 emissions using province-level information |
| 90 | Soytas, Sari, and Ewing [155] | Energy consumption, income, and carbon emissions in the United States |
| 91 | Stern [32] | The Rise and Fall of the Environmental Kuznets Curve |
| 92 | Dinda [6] | Environmental Kuznets Curve hypothesis: A survey |
| 93 | Cole [156] | Trade, the pollution haven hypothesis and the environmental Kuznets curve: Examining the linkages |
| 94 | York, Rosa, and Dietz [157] | STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts |
| 95 | Torras and Boyce [158] | Income, inequality, and pollution: A reassessment of the environmental Kuznets curve |
| 96 | Suri and Chapman [159] | Economic growth, trade and energy: Implications for the environmental Kuznets curve |
| 97 | Cole, Rayner, and Bates [160] | The environmental Kuznets curve: An empirical analysis |
| 98 | Panayotou [161] | Demystifying the environmental Kuznets curve: Turning a black box into a policy tool |
| 99 | Stern, Common, and Barbier [61] | Economic growth and environmental degradation: The environmental Kuznets curve and sustainable development |
| 100 | Selden and Song [56] | Environmental quality and development: is there a Kuznets curve for air pollution emissions? |

Note: The list is sorted chronologically.

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