Heliyon 8 (2022) e11521

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Review article

The evolution of the environmental Kuznets curve hypothesis assessment: A literature review under a critical analysis perspective

Patrícia Hipólito Leal [a,b], António Cardoso Marques [a,b,*]

[a] University of Beira Interior, Management and Economics Department, Portugal
[b] NECE-UBI, University of Beira Interior, Portugal

HIGHLIGHTS

- A EKC literature survey of more than 200 articles from 1998 to 2022.
- Comprehensive description of the EKC evolution and its functional specification.
- Three dilemmas of the EKC are explained by the Green Solow Model.
- EKC estimation is sensitive to functional specification.
- Climate finance and technological progress could influence EKC assessment.

ARTICLE INFO

Keywords:
Environmental kuznets curve
Green solow model
Environmental degradation
Economic growth
EKC growth path

ABSTRACT

Environmental changes based on factors like urbanization, population, economic growth, increase in energy consumption, and agricultural intensification are never far from the top of any agenda. The topics of environmental degradation and climate change cannot be confined to a single country or region but need to be addressed on a global scale. If the focus is on the relationship between environmental degradation and economic growth, then one hypothesis that is comprehensively used as an empirically model is the widely known Environmental Kuznets Curve. A substantial amount of research has been published about the Environmental Kuznets Curve, and this present study provides a detailed and extensive literature review of more than 200 articles from 1998 to 2022 to explain and assess its evolution. This literature review provides in detail the Environmental Kuznets Curve relationship under analysis, the additional variables included, the type of analysis and methods performed, the relationships obtained, and if the turning point is calculated. Furthermore, this comprehensive literature points out critical issues and gaps in the Environmental Kuznets Curve analysis. It is important to note that there are components that are not considered in the Environmental Kuznets Curve analysis. The Environmental Kuznets Curve only focuses on production and overlooks the impact of the consumption of imported goods on the environment. Consequently, environmental improvements from technological progress will be offset, and economic growth will result in more environmental degradation. This goes against the change in consumer behaviour which occurs with a rise in income, which is one basic assumption of the Environmental Kuznets Curve. The relocation of pollutant industries and consequent relocation of emissions could distort the emissions trajectory over the economic growth path and is also not considered in the Environmental Kuznets Curve analysis. On the other hand, the growth path traced by the inverted U-shaped is not efficient, and the environmental damage provoked in the first phases of the EKC might not be repairable. Therefore, technological progress, climate finance, and energy transition could improve the Environmental Kuznets Curve assessment.

* Corresponding author.
E-mail addresses: amarques@ubi.pt, acardosomarques@gmail.com (A.C. Marques).

https://doi.org/10.1016/j.heliyon.2022.e11521
Received 29 March 2022; Received in revised form 20 June 2022; Accepted 4 November 2022

1. Introduction

In the pre-industrial period, the earth's carbon circle was considered balanced. However, once the industrial revolution was underway, the burning of fossil fuels provoked a substantial increase in greenhouse gas (GHG) emissions. Society's extreme dependence on fossil fuels came from the necessity to meet rising energy demand. In light of this, the creation of wealth and energy consumption, that is, the income *per capita* of a country and the amount of energy used became indissociable. Since economic growth relies on increasing energy consumption, it goes hand in hand with rising GHG emissions. Therefore, over decades, economic growth has been achieved to the detriment of the environment, leading to global climate change. The current pandemic situation provides further evidence of this relationship. With economic activity severely affected, global emissions in 2020 were lower than the previous year [1].

Global warming and climate change are primarily a consequence of anthropogenic behaviours. The production of goods, generation of energy, agricultural activity, transport, and the heating and cooling of buildings are responsible for the release of, on average, 51 billion tons of GHG emissions into the atmosphere each year. The planet's biocapacity has been exceeded, and society is living in a state of ecological transcendence [2]. The rising risk of undesirable effects for human life, the economy and the environment come from increasing global warming. GHG emissions are the primary driver of and are responsible for rising global average temperature. GHG emissions have increased because of the growth of production, consumption, and population. Obsolete technology plays its part as well. The energy sector is strongly linked to the economy, policy, geopolitical demographics, financial market, and the environment [3]. Carbon dioxide emissions (CO_2), the primary greenhouse gas, are closely related to economic growth, human well-being, financial development, industrialization and urbanization [4].

Throughout the years, there have been many discussions about the climate change path and the future of the environment. The Brundtland Commission (also known as the World Commission on Environment and Development (WCED)), in the Brundtland report of 1987, raised concerns about the capacity of the environment to satisfy the present and future needs of humanity [5]. In such a way, a conflict between traditional economic development and environmental well-being arose [6, 7]. Sustainable development includes appropriate care of the environment. Since the 1990s, mitigation strategies have been the focus of discussion in both developed and developing countries. To discuss these strategies, summits and agreements were established, such as the Earth Summit conference in 1992 and the Kyoto Summit in 1997. After these, the Conference of Parts (COP), particularly COP21 (Paris in 2015), became one of the most relevant conferences, where a limit on the increase of the global temperature of less than 1.5 °C above pre-industrial levels was established, giving rise to the Paris Agreement. This agreement, which is an international treaty on climate change and is considered a valuable landmark in the climate change mitigation process, defined the necessity to meet every five years to re-evaluate the current state of climate change. The 26th United Nations Climate Change Conference of the Parties (COP26), five years apart from the Paris agreement, was the time for countries to strengthen climate action and define ambitious goals.

The Environmental Kuznets Curve (EKC) is one of the most prevalent methods to analyse environmental performance. The EKC is based on an inverted U-shaped curve created by Kuznets in 1955 [8]. It was initially designed to study the relationship between income per capita and income inequality. The EKC became more popular when the inverted U-shape started to be adopted in environmental studies. Since then, it has been widely and intensely used as a theoretical framework to study the relationship between yield and environmental degradation [9]. The emergence of the EKC provoked a change in environmental discussion focus. Before the EKC, concerns were focused on the limited capacity of the planet to absorb urban and industrial waste. With the EKC, the environmental concerns changed from environmental resource scarcity to the inevitable necessity of income growth to deal with pollution [10].

The EKC defines the trajectory of pollution over time and the income resulting from the economic development of an economy [11]. Therefore, the EKC is commonly divided into three phases: the early stages of economic development, the turning point, and the later stages of economic development. Briefly (a detailed definition is provided in the following section), considering economic growth over time, the first phase is characterized by an intensive use of resources and a rapid increase in environmental degradation. The second phase, the turning point, is reached when a certain level of income is achieved, and a change in the pollution trajectory occurs, which leads to the third phase, characterized by environmental degradation mitigation. Bringing into mind the indissociable relationship described at the beginning of this section, the early stages of economic development represent that. However, when the turning point is reached, income starts to be dissociable from emissions and environmental degradation, leading to the later stages of economic development, where there is the dissemination of clean technology and innovation.

The EKC has been widely applied in the environment-energy-economics literature, and innumerable researchers have attempted to validate the inverted U-shaped between environmental degradation and income. Therefore, the EKC has been assessed for the most diverse contexts (country/ies, time span, variables, and methods) yet there is still no consensus on the results. With this in mind, this review article aims to answer the following research questions: (i) Is the EKC keeping up with the increasing complexity of environmental issues?; (ii) What has been influencing the inverted U-shaped curve?; and (iii) How can the fit of the EKC be improved to meet the complexity of the economic growth and environmental degradation relationship? To answer these questions, an extensive survey of the EKC literature is provided with the objective to (i) describe the evolution of the EKC assessment and provide an integrated overview of the current state of EKC knowledge; (ii) identify the factors that influence the EKC validation; and (iii) describe research insights, existing gaps, and provide improvement needs.

Overall, this research intends to be a valuable tool for EKC researchers and is differentiated from the existing review articles by providing a detailed description of the EKC background, which includes the origins and conceptual framework, an explanation of the EKC shape, and the distinct phases of development, issues, and challenges of the EKC analysis, and the factors that most affect the EKC shape. Besides that, this paper also describes the close relationship between the EKC and the macroeconomic Green Solow Model. Furthermore, this literature review provides an embracing description of the evolution of the EKC analysis through an extensive literature survey and specifies each detail of the analysis of more than 200 papers from 1998 to 2022. The analysis of the EKC literature for this extended period allows us to understand what is currently analysed, in addition to the evolution of the EKC assessment over the years. This literature survey is being conducted so as to be an intuitive tool for researchers to efficiently find specific information about the procedures used in the literature focused on the EKC study, namely: (i) country (ies) and time period; (ii) variables analysed on EKC validity; (iii) additional variables included in the EKC analysis; (iv) types of analysis and method(s) employed; (v) relationships obtained, and (vi) turning point. This literature survey conducts a critical analysis of the EKC approach, identifying critical issues, proposing improvements, and future lines of research.

This paper is divided into five sections. Section 2 presents the origins, conceptual framework and shape of the EKC. Section 3 follows, where the details of the evolution of the EKC analysis can be found. Section 4 describes the gaps in the EKC assessment, and lastly, in Section 5, the conclusions of the research are given.

2. Origins, conceptual framework, and shape of the EKC

The EKC was preceded by the Research of Kuznets [8], on which the EKC is based. Simon Kuznets won a Nobel prize for his framework based on the economic and social structure of national development procedures

[12]. The results of the research of Kuznets [8] disclosed an inverted U-shaped relationship between income per capita and income inequality. According to Kuznets [8], the inverted U-shaped relationship revealed an unequal income distribution in the early stages of income growth that moves towards equal income distribution with increasing economic productivity in the later stages of economic growth. Therefore, Kuznets [8] specified that the transition from a pre-industrial to an industrial development firstly led to income inequality. This is followed by a rising income per capita together with superior income equality. The EKC attracted a lot of attention from policymakers, theorists and empirical researchers and started to be widely used in environmental studies [13, 14] through the seminal research of Grossman and Krueger [9], carried out in 1991. They revealed that the relationship between income per capita and environmental degradation, like the income per capita and income inequality of Kuznets [8], also follows an inverted U-shaped curve.

In the early 1990s, the main idea in economics was "*too poor to be green*" [15]. According to Beckerman's [15] point of view regarding the effect of economic growth on environmental degradation, the author argues that there is: «*clear evidence that, although economic growth usually leads to environmental deterioration in the early stages of the process, in the end, the best and probably the only way to attain a decent environment in most countries is to become rich*». This view reflects the basic philosophy of the EKC theory. The World Development Report in 1992 argues that some environmental problems are aggravated by the growth of economic activity, and it suggests that accelerated equitable income growth will make it possible to achieve higher world output and improved environmental conditions [16, 17]. This proposal lays the foundation of the EKC literature. A robust foundation for the EKC is provided by Dinda [18], Stern [19], and Kaika and Zervas [20], and it is presented throughout this paper. Kwabena et al. [21] and Olale et al. [22] provide a survey of theoretical research related to the EKC.

2.1. Conceptual framework of the EKC

The EKC is commonly interpreted in two ways. One is through the division into two phases, namely the early and later stages of economic development. The early stages are defined, on the one hand, by a decreasing capacity of ecosystem regeneration as a consequence of intensive use of resources that lead to a rising ecological footprint and pollution [13, 23]. On the other hand, the early stages are linked with lax environmental regulations associated with a low capacity to pay for environmental conservation [24]. The later stages are characterized by mitigation of environmental degradation resulting from the dissemination of clean technology and innovation, society environmental awareness, and effectiveness and institutional quality associated with an increase in the level of income [13, 23]. In addition, these stages are also characterized by two effects, i.e., policy effect and income effect. The policy effect consists of greater public concern about the environment, which leads to rigorous regulatory requirements. At the same time, the income effect consists of the increase in income that leads to an increase in the willingness to pay for environmentally-friendly features [24]The other way that the inverted U-shaped curve is commonly interpreted is when economic development is divided into three phases of [13, 20, 25], namely: (i) the pre-industrial economy, mainly characterised by primary sector and low levels of income; (ii) the industrial economy, constituted by the secondary sector and associated with middle-income levels; and (iii) the post-industrial economy, formed by the tertiary sector and services, and associated with higher levels of income. In the pre-industrial economy, economic activity is limited and results in a natural resource abundance and reduced formation of waste [20, 26]. In this phase, the use of pollutant technology, the lack of environmental awareness, and the prioritisation of economic growth result in rising environmental degradation [27]. The industrial economy is characterised by natural resources that are starting to run out and increasing waste accumulation because of industrialisation. In this phase, a positive relationship between economic growth and environmental deterioration is verified, and it occurs before the turning point is achieved. The third phase of economic development is characterised by a structural change in the economy, changing to information- and technology-intensive industries and a services-directed economy. This change is linked with the reinforcement of environmental regulations, the use of cleaner and efficient technology, and a strengthening of environmental awareness, resulting in a mitigation of environmental degradation [20, 26]. In this phase, a negative relationship between economic growth and environmental deterioration is verified, and it occurs after the turning point has been reached.

2.2. Shape of the EKC

The EKC consists of an inverted U-shaped curve between income and environmental degradation; that is, the EKC defines the pollution trajectory over time and income resulting from economic development [11]. The EKC is a long-run concept [28]. In light of this, the EKC reflects a dynamic environment–economy relationship concentrating on long-run processes of change [29]. The EKC is assessed through the nature of the effect of the income and its square (to ensure the concavity of the curve) on environmental degradation. The inverted U-shaped curve is validated through the significant and positive coefficient and elasticity of income simultaneously with the significant and negative coefficient and elasticity of income squared. Therefore, considering β_1 as the coefficient of income and β_2 as the coefficient of income squared, both in the longrun, the EKC is verified according to the condition $\beta_1 > 0 \Lambda \beta_2 < 0$ (in which this paper is focused).

The assessment of the EKC could lead to the validity of the following conditions (see Figure 1):

1. $\beta_1 = \beta_2 = 0$. No relationship between x and y.
2. $\beta_1 > 0 \Lambda \beta_2 = 0$. Linear relationship between x and y.
3. $\beta_1 < 0 \Lambda \beta_2 = 0$. Decreasing relationship between x and y.
4. $\beta_1 < 0 \Lambda \beta_2 > 0$. U-shaped relationship.
5. $\beta_1 > 0 \Lambda \beta_2 < 0$. Inverted U-shaped relationship—EKC.

where, y is the environmental indicator and x is the income.

Besides these ones, two more conditions might be obtained in the EKC assessment. These two imply the inclusion of the third polynomial, income cubed (β_3).

6. $\beta_1 < 0, \beta_2 > 0 \Lambda \beta_3 < 0$. Opposed to the N-shaped curve.
7. $\beta_1 > 0, \beta_2 < 0 \Lambda \beta_3 > 0$. Cubic polynomial or N-shaped curve.

Throughout the years, several authors have highlighted factors that affect the shape of the inverted U-shaped curve. Panayotou [13], one of the first authors assessing the EKC hypothesis, disclosed that policy distortions, such as market breakdowns, under-pricing of natural resources, and subsidies on economic structures intensive in carbon and energy affect the slope of the inverted U-shaped curve. In turn, Kaika and Zervas [20] identified the following factors: institutional framework and governance, consumers' preferences, and equity of income distribution. The willingness of governance to implement environmental regulation is considered crucial to mitigate environmental degradation [30]. When governance institutions are weak, less effective or corrupted, this could affect the shape of a possible EKC and change the turning point to higher income levels [31].

Many researchers have assessed whether the equity of income distribution affects the EKC pattern [32, 33, 34]. To assess this, the crucial question is whether economic growth leads to equitable income distribution or increases income inequality. The automatic thought could be that economic growth leads to a more equitable income distribution that consequently leads to an improvement in public awareness of environmental degradation and the imposition of suitable environmental regulations. Income distribution is the distribution of power, and pollution

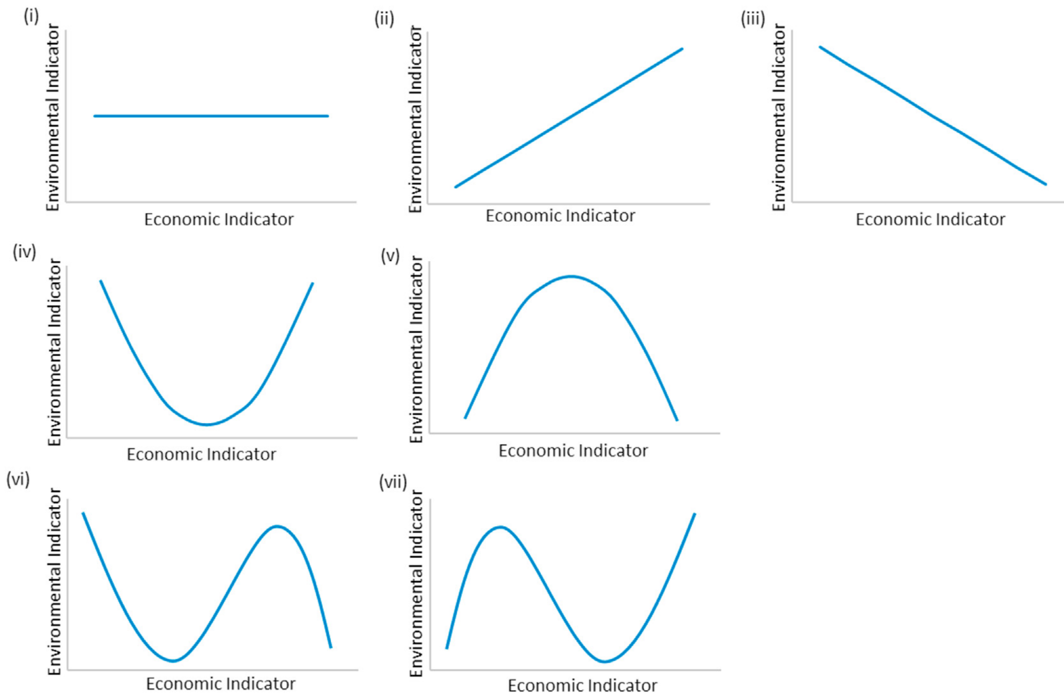

Figure 1. Graphical representation of the relationship between an Environmental Indicator and an Economic Indicator. *Legenda*: (i) No relationship between x and y; (ii) Positive relationship between x and y; (iii) Decreasing relationship between x and y; (iv) U-shaped relationship between x and y; (v) Inverted U-shaped relationship between x and y; (vi) Inverted N-shaped relationship between x and y; and (vii) N-shaped relationship between x and y.

decreases or increases depending on the gap of power between the citizens who suffer due to pollution and the ones that benefit from pollution [32]. Therefore, if income inequality worsens, this will lead to continuing environmental deterioration due to the fact that the ones who suffer from environmental degradation will not have the economic conditions to impose environmental regulations on the ones that would benefit from it [34].

In the recent literature, the factors most considered to affect the shape of the EKC are the scale, composition, and technique effect; income elasticity of environmental quality; and international trade [25]. The scale, composition, and technique effect are the three stages used to characterise the relationship between environmental degradation and economic development [9]. The scale effect denotes environmental degradation as a consequence of economic development, that is, a negative impact of economic growth on the environment. The negative impact is a consequence of intensive use of natural resources to supply an increasing demand and consequent increasing production output. This intensive energy consumption comes mainly from fossil fuels that are a cheap, abundant, and easy-to-transport energy source. The composition effect is characterised by structural changes in the economy, which could provoke both negative and positive impacts of economic development on the environment. A change from an economy directed to the primary sector to energy- and carbon-intensive industries results in a negative impact. In contrast, a shift from pollution-intensive industries to an economy directed to the services sector results in a positive impact [23]. The technique effect denotes a mitigation effect of economic development on environmental degradation. This is explained by a higher level of income that leads to investing in research and development, replacement of dirty and outdated technologies, and strengthened environmental regulations.

The income elasticity of environmental quality demand consists of the ratio between the variation in the environmental quality demand and the variation in income level. The role of this factor on environmental degradation mitigation is highlighted [18, 23, 35]. The income elasticity denotes that with rising economic development, society intuitively lives in a higher standard and yearns for quality instead of quantity. Therefore, there is greater environmental awareness and availability of money to pay for a cleaner environment [36], which leads to an adjustment in consumer behaviour, for instance, opting for energy-efficient and environmentally friendly products and services [37, 38] and donating to environmental protection organizations [18].

International trade is considered one of the most crucial factors explaining and affecting the shape of the EKC, and the EKC pattern may appear as a result of it [39, 40, 41]. In light of this, trade policies are crucial to explain the EKC. Trade openness leads to economic expansion through the request to increase the production of goods to satisfy its exports. Broadly speaking, countries tend to become specialized in sectors in which they have a competitive advantage as a consequence of trade liberalization. However, on the one hand, if these sectors derive from weak environmental regulation, trade liberalization induces environmental damage, which consequently results in an industrial process with high pollution abatement costs [9]. On the other hand, when income and environmental degradation significantly increase, stringent environmental regulations are imposed and implemented, which consequently lead to the shift of pollution-intensive goods production to other countries. These countries are usually low-income countries with weak and lax environmental legislation [18, 20]. This is defined as the Pollution Haven Hypothesis (PHH). The lax environmental regulation in the developing countries provides a comparative advantage for the developed economies, which leads to the reduction of environmental degradation in the developed economies while increasing it in the developing ones [42]. An inverted U-shaped curve is obtained through two phases. Firstly, the export of goods in a developed country causes the upwards slope of the curve (early stages of economic development). After that, the import of goods from developing countries causes the downward slope of the curve (later stages of economic development). The downward slope of the curve is reported as the PHH [18].

2.3. The EKC and the green solow model

The assessment of the EKC occurs through the analysis of environmental degradation over an increasing income. Economic growth is a macroeconomic indicator, and the Solow Model is considered the main model of modern macroeconomics. Brock and Taylor [43] developed a theoretical framework to explain the EKC. By incorporating environmental pollution into the Solow Model [44], the authors created the Green Solow Model. According to Brock and Taylor's [43] pollution data and their empirical work on the EKC, three dilemmas were revealed, and the Green Solow Model provides an explanation for each one. The dilemmas are namely: (i) the ongoing huge decline in emissions intensity simultaneously with almost stagnant pollution abatement costs; (ii) what feature gives the humped-shape profile to the pollution levels when it is graphically represented against income per capita or time; and (iii) the fragile empirical results of cross-country analysis indicate that the EKC is not validated, or the problem is applying empirical approaches that are subject to extensive variance.

To assess the first dilemma, the authors [43] analysed two concrete cases, the United States (US) and Europe. In both cases, while a huge variation in emissions occurred, an insignificant variation in the pollution abatement expenditures/costs was observed. However, in both cases, the EKC pattern is graphically visible when emissions are graphed against time and an income increase over the same period is considered [43]. In the US, a huge variation in emissions has taken place over the last 20 years while simultaneously, pollution abatement costs have remained at less than one-half of 1% of Gross Domestic Product (GDP) for the same time period [45]. In Europe, an emissions reduction of 4–5% per year has been observed alongside a pollution control cost with an average of only 1–2% of GDP. To provide answers to this dilemma, the authors considered exogenous technological progress in abatement and a fixed intensity of abatement.

Theories based on strict environmental policies expect growing costs to mitigate environmental degradation. In a scenario of a world that does not have technological progress for this, a huge investment in pollution control is needed [46]. Technological progress in goods production and abatement leads to continual growth alongside increasing environmental quality. Through the formulation and development of the model, the authors conclude that technological progress in goods production is required to produce income growth. Besides that, technological progress in abatement must go above growth in aggregate output for pollution to decrease and, consequently environmental quality to increase. These two conditions make sustainable growth guaranteed. In light of this, technological progress in abatement increases the effectiveness of the share of output applied to reducing environmental damage. Output growth results in an increase in emissions; however, then emissions decrease as technology is applied to offset environmental damage.

The second dilemma refers to the feature that gives the humped-shaped profile to emissions when graphed against time or income. This dilemma consists of the analysis of the existence of the turning point, which allows the humped-shaped through inverting the emissions' trajectory. Through the Green Solow Model, and as mentioned in the first dilemma, sustainable growth is guaranteed when technological progress exists in production (it is essential to produce income growth), and when technological progress in abatement goes further than the growth of aggregate output (this mitigates pollution). In addition, by recurring to the Cobb-Douglas function, Brock and Taylor [43] conclude that if an economy has small initial capital stock, then emissions firstly increase and then start to decrease as development continues. Therefore, the emissions humped-shaped EKC profile is obtained if growth is sustainable, and simultaneously the stock of capital at the turning point is higher than the initial stock of capital. This leads to an initial positive growth rate of aggregate emissions that become negative in finite time. The answer to the first dilemma also helps in understanding the second dilemma. Through technological progress in abatement, a time profile of increasing and then decreasing emissions, with income per capita growing along a path of sustainable growth, is generated.

The third dilemma is related to the variation that samples and the estimation procedure provoke on the EKC empirical regressions. The answer for this dilemma starts in the second dilemma by recurring to the Cobb-Douglas function to assess the initial conditions, which are the initial technological progress in goods production, labour and units of pollution. Different profiles of income per capita and emission over time are obtained as a consequence of economies with different initial conditions. Considering this, heterogeneity could explain the sensitivity of the EKC results to the sample. Therefore, this explains the absence of a consensus on the EKC results in country-level data and the possible difference between the EKC empirical results in cross-country analysis and the country-level analysis of the same countries. The cross-country analysis that includes developed and developing countries is a plausible example to demonstrate the effect of heterogeneity. Clearly, these countries differ in more than the initial condition. The heterogeneity in this analysis may further confound the estimation. According to the EKC literature, the time period, the countries sampled, and even the environmental indicator chosen could provoke a change in the shape of the estimated EKC. Even for similar countries, the EKC profiles are not unique due to the differences in the initial conditions.

3. Getting inside the evolution of EKC analysis

The first literature on the theory of the EKC was focused on developing models that replicated the inverted U-shaped curve relationship. Considering the increasing complexity of reality (such as technological development, the introduction of renewable energy sources in the energy sector, increasing industrialization and globalization) the EKC analysis has had to be continuously improved. Throughout the EKC literature, diverse literature surveys were developed. However, on the one hand, most of the articles that provide a comprehensive contextualization of the EKC literature are not focused on the EKC theoretical background or critical analysis, instead, they are focused on an empirical analysis [47, 48, 49, 50]. On the other hand, articles focused on the evolution of the EKC literature use specific approaches to assess the EKC literature, such as meta- and bibliometric analysis [25, 51, 52], which provide the research areas on the subject, the author's contribution and most cited authors, journals that are publishing on the subject, and keywords used. Differentiated from these, the present review article is focused on providing an extensive and comprehensive contextualization of the EKC framework, the evolution of the literature, current analysis, and critical analysis that addresses gaps, issues, and improvement needs. Besides that, and as a prominent contribution to the literature, this article provides a useful and intuitive tool for EKC researchers where they can find detailed information about the EKC analysis in more than 200 articles since the country (ies) and time period under analysis, and the variables for each EKC relationship is analysed, until each additional variables included, the types of analysis and method(s) employed, the relationship obtained for each sample analysed, and if the turning point is calculated.

The procedure for an analysis of the EKC focuses on two key areas: the selection of the EKC relationship variables and the selection of the EKC functional specification. The latter includes the method, additional variables, temporal period, and cross-country or individual analysis. This section demonstrates how the selection of each element has progressed in the EKC literature. Some examples are displayed in tables (just a few examples from the substantial number of articles presented in the tables in the supplementary data), providing an organised and intuitive literature review of the EKC literature. The tables are organized into the EKC relationship analysed, approaches used, additional variables included, countries analysed (individual or cross-country), and the relationship obtained. This schematisation allows not only an observation of the evolution of the EKC analysis but also an identification of gaps in the analysis. The third dilemma identified by Brock and Taylor [43] regarding the variation that the sample and the estimation procedure provoke on the EKC empirical regressions is also explored.

Table 1. Variables of EKC relationship.

Environmental indicators		Other types of indicators	
Authors	Variables analysed on EKC relationship	Authors	Variables analysed on EKC relationship
[58]	(i) CO_2 emissions—GDP	[39]	Consumption of Primary Commercial Energy–GDP
	(ii) Ammonium—GDP		
	(iii) Nitrous Oxide—GDP		
[59]	6 Footprint components (Built, Carbon, Cropland,	[60]	Pollution Abatement Costs–Gross State Product
	Fishing, Forest, Grazing)—GDP	[61]	Income Inequality–Tourism Revenue
[63]	Municipal Solid Waste—GDP	[62]	Load Capacity Factor—GDP
[64]	(i) Timber output—GDP and FDI	[65]	(i) Primary Energy Consumption–GDP
	(ii) Afforestation Area—GDP and FDI		(ii) Oil Consumption–GDP
[66]	(i) Territory-based CO_2 emissions—GDP		(iii) Natural Gas Consumption–GDP
	(ii) Consumption-based CO_2 emissions—GDP		(iv) Coal Consumption–GDP
			(v) Hydroelectricity Consumption–GDP
[67]	(i) Sulphur Dioxide emissions- GRP	[68]	Energy Consumption–GVA
	(ii) Industrial Solid Waste–GRP	[69]	Coal Consumption–GDP
	(iii) Industrial Wastewater Discharge—GRP		
[70]	Haze Pollution–GDP	[71]	(i) Renewable Energy Consumption–GDP
[72]	(i) Water Consumption—GDP		
	(ii) Industrial Water Consumption—GDP		(ii) Non-Renewable Energy Consumption–GDP
	(iii) Non-Industrial Water Consumption—GDP		
[73]	$PM_{2.5}$ emissions–GRP	[74]	(i) Domestic Material Consumption—GDP
			(ii) Material Footprint–GDP
[75]	(i) CO_2 emissions—GDP	[76]	Electricity Intensity–GDP
	(ii) CO_2 Intensity—GDP		
	(iii) CO_2 emissions by sector—GDP		
[77]	Residential CO_2 emissions–GDP	[78]	Fossil Fuel Electricity Production–GDP
[79]	Agricultural CO_2 emissions—Agricultural Economic Growth	[80]	Energy Intensity–GDP
[81]	(i) Wastewater Discharge—GDP	[82]	Final energy Consumption in Households–GDP
	(ii) Wastewater Discharge—Urbanization		
[83]	Chromium—GDP	[84]	Fossil fuel share in energy mix–GDP
[85]	(i) CO_2 emissions of solid—GDP	[86]	(i) Environmental Crimes–GDP and Education
	(ii) CO_2 emissions of liquid—GDP		
	(iii) CO_2 emissions of gaseous—GDP		(ii) Environmental Crimes–Household income and Education
	(iv) CO_2 emissions aggregate—GDP		
[87]	CO_2 emissions—Remittances	[88]	Noise Pollution—GDP
[89]	(i) Environmental Degradation Index—HDI	[90]	(i) E-waste—GDP
	(ii) Ecological footprint—HDI		
[91]	(i) CO_2 emissions—GDP	[92]	**Energy-Resource Depletion**: (i) Energy Depletion—GDP (ii) Net Forest Depletion—GDP (iii) Natural Resource Depletion—GDP **Climate Change**: (iv) Perfluorocarbon emissions—GDP (v) $PM_{2.5}$ emissions—GDP (vi) Sulphur Hexafluoride emissions—GDP (vii) GHG emissions—GDP **Health Resources:** (viii) Tuberculosis—GDP (ix) Infant Deaths—GDP (x) Health Expenditures–GDP
	(ii) Sulphur Dioxide—GDP		
	(iii) Volatile Organic Compounds—GDP		
	(iv) Nitrogen Oxides—GDP		
	(v) Carbon Monoxide—GDP		
[93]	Composite Index of Environmental Performance—GDP		

Notes: CO_2 denotes Carbon Dioxide; FDI denotes Foreign Direct Investment; GDP denotes Gross Domestic Product; GHG denotes Greenhouse Gases GRP denotes Gross Regional Product; GVA denotes Gross Value Added; HDI denotes Human Development Index; $PM_{2.5}$ denotes Particulate Matter (2.5 μm).

3.1. The EKC relationship: from environmental to other types of indicators

The variables selected to assess the EKC, that is, the variables for which a relationship that follows the EKC is assessed, are originally an environmental indicator and an economic indicator. However, over the years, in place of the environmental indicator, several other types of indicators have been used to assess the EKC. Considering the EKC literature collected in this paper, the relationship between CO_2 emissions and GDP is the most frequently analysed [4, 53, 54, 55, 56, 57] (see supplementary data), which makes CO_2 emissions the environmental indicator most often used (about 100 articles out of 200 collected in this paper). Notwithstanding, throughout the years, innumerable environmental indicators have been used to assess the EKC, such as air pollution, ecological footprint, waste, afforestation, water consumption, and others. However, not only are environmental indicators assessed. Besides these indicators, also energy consumption, pollution abatement costs, environmental crimes, and health indicators have been analysed. In Table 1, the diversity of EKC relationships analysed are displayed.

In respect of the environmental indicators, choosing among diverse indicators of environmental degradation is challenging considering the complexity and multiple dimensions of environmental problems. Therefore, the selection of an indicator takes place between numerous types; however, atmospheric indicators have been the most abundant. This type of indicator includes emissions of CO_2, GHG, Nitrous Oxide (N_2O or NO_2), and others. The pollutant under analysis could be local or global. Some studies use local pollutants, such as Sulphur Dioxide (SO_2), water pollution and deforestation, while others use global pollutants, such as CO_2 emissions. Environmental degradation indicators are the most often chosen to assess the EKC. However, the indicator does not have to be of degradation; it could be of environment recovery, concern, or protection. Besides the atmospheric indicators, (i) land and forests; (ii) oceans, seas, coasts, and biodiversity; and (iii) freshwater indicators have also been analysed [25].

The various indicators used in assessing the EKC relationship throughout the literature have given rise to different forms of this model. Consequently, the EKC concept is often converted depending on the type of indicator used in the relationship. Energy indicators (e.g. renewable energy consumption, non-renewable energy consumption, energy consumption, energy intensity, and others) are frequently used to assess the EKC relationship, from which emerge adaptations of the EKC depending on the energy indicator used, such as the Renewable Kuznets Curve. Therefore, it is common in the literature to see adaptations from the EKC linked to the specific indicator used instead of the usual environmental indicators. Throughout this review article, several EKC forms are addressed (see Table 1 and supplementary data).

The selection of the EKC relationship to analyse is one of the first steps in EKC studies, and this choice influences the validation of the EKC. The empirical results of the EKC are not unique, and they are sensitive to the variables under analysis, as is the type of pollutant. One example of that is the study developed by Shafik and Bandyopadhyay [11], which analysed ten indicators of environmental pressure, and from these ten, only two followed the EKC. In light of this, it is notable to mention the degree of sensitivity of the EKC regarding the environmental degradation indicator under analysis. Another example is the study developed by Altıntaş and Kassouri [94], which analysed the EKC relationship between CO_2 emissions and GDP, and ecological footprint and GDP, for the same samples of countries and time period, and with the same approaches. They obtained different results for each environmental indicator. Ecological footprint validated the EKC, while CO_2 emissions revealed a U-shaped curve. The selection of the environmental indicator or other indicator used in the EKC analysis gives rise to a gap in the literature, which confirms that the inverted U-shaped curve (EKC) is only demonstrated for some environmental indicators. This is, according to Liu [95], due to the lack of consistent data, assessing the EKC for industrial pollution and human health had not been possible.

Besides the immense variety of environmental or other types of indicators applied in the hypothesis, variables chosen for the economic indicator also have been diverse, although not to the same extent. GDP is the most frequent economic indicator used in the EKC relationship. However, over the years, other indicators have been used, such as Gross Regional Product (GRP), Foreign Direct Investment (FDI), Gross Value Added (GVA), Gross State Product, income inequality, economic complexity index [96], air transport passenger [97], manufacturing sub-sector output [98], Oil Rents [99], and others. In the selection of the economic indicator, not only does the indicator used in the EKC relationship influence its validation, but also the data analysed. Kacprzyk and Kuchta [49] developed an analysis using different GDP data for analysing the EKC between GDP and CO_2 emissions. The use of three different measures of GDP revealed ixed results.

Table 2. Additional variables.

Energy	Renewable energy consumption; Non-renewable energy consumption; Energy consumption; Energy consumption by sector; Oil consumption; Coal consumption; Biomass energy consumption; Hydroelectricity consumption; Agricultural energy consumption; Electricity consumption; Nuclear electricity output; Electricity production from non-renewable sources; Renewable electricity production; Energy Intensity; Energy price; Energy efficiency; Electrification; Energy taxes; Energy innovation.
Economic	Trade openness; Imports; Exports; Unemployment; FDI; Industry added value; Agriculture added value; Gross capital formation; Financial development; Share of manufacturing in GDP; Industrialization; Fiscal policy index; Income inequality; Corruption; Risk of poverty; Governance; Gross saving; Government expenditure on educations; Economic complexity index; Oil price; Merchandise trade; Labour productivity; Regulation; Tourism; Index of economic freedom of Heritage Foundation; Sanitation investment; Industrial structures; Education; Human Development Index; Political stability; Government effectiveness; Total factor productivity; Economic stability; Health expenditures; Research and development.
Environment	Environmental cleaning capacity; Atmospheric environmental regulations; Greening level; Cooling degree days; Temperature over three summer months; Temperature over three winter months; Climate conditions; Water resources; Green patent counts; Environmental regulation; Quality of the institutional environment; Biocapacity; Stringency of environmental regulation; Enforcement of environmental regulations.
Technology	Technological innovation; Information and communication technologies; Technology level.
Sociodemographic	Population density; Population; Urbanization; Ratio of Females; Age ranges; Geographical location; Globalisation; Area; Density.

3.2. EKC functional specification: approach, additional variables, time period and countries sample

After selecting the variables to assess the EKC relationship, follows the adoption of the functional specifications, which consists of choosing the method/approach and the structure of the model. The structure of the model includes the additional variables beyond the variables of the EKC relationship, the time period, and the sample of countries to analyse.

3.2.1. Additional variables

The additional variables are those included in the estimation beyond the variables for which the EKC relationship is assessed. With the increasing complexity of reality, the additional variables included in the estimations are innumerable and of several types. According to Kaufmann et al. [100] and Itkonen [101], the inclusion of additional controls influences the EKC assessment and the results of the EKC estimation. Table 2 displays a summary of the additional variables.

Energy consumption quickly became the most common variable added to the EKC estimations [102, 103, 104, 105, 106]. Considered as one of the main drivers of environmental degradation and climate change, energy consumption has been analysed with most of the environmental indicators. The analysis of energy consumption has improved over the years. It started with the analysis of energy consumption in its aggregate form, as a whole, and evolved by analysing energy consumption by types of technology, renewable and non-renewable, and after that by energy sources, such as coal, oil, gas, nuclear, solar, wind, and others. The inclusion of energy consumption in the EKC assessment keeps up with any improvement in energy consumption analysis [107, 108, 109, 110, 111, 112]. However, the inclusion of energy consumption as one of the CO_2 emissions determinates could cause an underestimation of both the sensitivity of CO_2 emissions to income growth and the turning point of the EKC [101, 113]. This occurs because the two data series are related by construction. Consequently, any other variable included in the model can only explain the carbon intensity of energy consumption and not the CO_2 emissions level [101].

Table 3. Approaches performed.

Time series data		Panel data	
Authors	Method(s) employed	Authors	Method(s) employed
[103]	(i) VECM	[54, 115]	(i) FMOLS
	(ii) GARCH		(ii) DOLS
			(iii) VECM
[116]	(i) Toda–Yamamoto	[117]	AMG
	(ii) Fourier Toda–Yamamoto		
[35, 118, 119]	(i) ARDL	[103]	(i) VECM
	(ii) Granger causality		(ii) GARCH
[120]	(i) Toda–Yamamoto	[121]	(i) PMG
	(ii) Generalized Forecast Error Variance Decomposition		(ii) MG
	(iii) Generalized Impulse Response		(iii) DFE
			(iv) SFE
[122]	OLS	[102, 123]	FMOLS
[124]	DOLS	[60]	OLS
[125, 126]	ARDL	[39, 129]	FGLS
[127, 128]		[130]	(i) FGLS
			(ii) GMM
[107]	(i) ARDL	[131]	(i) SUR
	(ii) DOLS		(ii) GMM
	(iii) FMOLS		(iii) 2SGMM
	(iv) CCR		(iv) SYS–GMM
	(v) VECM		(v) Sys2Step
[53, 132, 133]	(i) ARDL	[134]	(i) FE-OLS
	(ii) VECM		(ii) FMOLS
			(iii) DOLS
			(iv) MMQR
[135]	(i) ARDL	[91]	(i) PCSE
			(ii) GLS
	(ii) FMOLS	[136]	(i) CS-ARDL
			(ii) AMG
			(iii) CCEMG
	(iii) DOLS	[137]	Simultaneous–equations
	(iv) CCR		
	(v) VECM		
	(vi) Sasabuchi–Lind–Mehlum U test		
[98]	(i) ARDL	[78]	Partial adjustment model
	(ii) DOLS		
	(iii) FMOLS		
	(iv) Lind and Mehlum test		
[138]	Coefficient of Cross–Correlation	[67]	(i) Pooled OLS
			(ii) SDM
[139]	Quantile ARDL	[70]	SGVAR
[140]	STSM	[63]	(i) SLM
[75]	(i) NARDL		(ii) SEM
	(ii) ARDL		(iii) LSDV
			(iv) Convergence
[62]	Dynamic ARDL	[58]	(i) VAR
			(ii) OLS

Notes: ARDL denotes Autoregressive Distributed Lag; CCEMG denotes Common Correlated Effects Mean Group; CCR denotes Canonical Cointegrating Regression; CS denotes Cross-Sectional; DFE denotes Dynamic Fixed Effect; DOLS denotes Dynamic Ordinary Least Square; FGLS denotes Feasible General Least Squares; FMOLS denotes Fully Modified Ordinary Least Square; GARCH denotes Generalized Autoregressive Conditional Heteroskedasticity; GLS denotes Generalized Least Squares; GMM denotes Generalized Method of Moments; LSDV denotes Least Square Dummy Variable; MG denotes Mean Group; MMQR denotes Method of Moments of Quantile Regression; OLS denotes Ordinary Least Square; NARDL denotes Nonlinear Autoregressive Distributed Lag; PCSE denotes Panel Corrected Standard Errors; PMG denotes Pooled Mean Group; SDM denotes Spatial Durbin Model; SEM denotes Spatial Error Model; SFE denotes Static Fixed Effect; SGVAR denotes Semi-Parametric Global Vector Autoregressive Model; SLM denotes Spatial Lag Model; STSM denotes Structural Time Series Model; SUR denotes Seemingly Unrelated Regression; SYS-GMM denotes System Generalized Method of Moments; Sys2Step denotes Two-Step Dynamic System Generalized Method of Moments; VAR denotes Vector Autoregressive Model; VECM denotes Vector Error Correction Model; 2SGMM denotes Two-step Dynamic Generalized Method of Moments.

3.2.2. *Approach or method*

At the beginning of the EKC literature, countless studies focused on the proximate aspects of the theory, which consequently took to reduced-form models. These models connect income and pollution directly through estimations and tests of correlations between indices of environmental condition and development [114]. The reduced-form models are simpler and are of limited utility [12]. Therefore, the need arose to improve the EKC analysis, and the studies started to employ structural equation models and included intervenient variables, which in turn, connected development processes with environmental outcomes. In light of this, and until the present day, the EKC has been assessed through innumerable approaches/methods and econometric procedures. Table 3 displays some examples of the methodologies applied (more examples are given in the supplementary data).

The econometric issues are one of the main topics criticised in the EKC estimation. Therefore, the methods employed in the EKC analysis give rise to significant criticism. The EKC is commonly estimated through reduced-from regressions, which is frequently disparaged by several researchers [141, 142, 143]. Furthermore, empirical EKC research commonly uses standard cointegration techniques that are often considered unsuitable [19, 144, 145]. Kacprzyk and Kuchta [49] provide further explanations for this inadequacy. According to Gill, Viswanathan and Hassan [10], the EKC literature is not econometrically demanding, and the empirical results of the EKC analysis are very sensitive regarding the functional form of the model. Considering this, it is fair to say that the EKC assessment is sensitive and influenced by the model or econometric procedure used (please see Table 4, 5 and 6 displays several examples of this).

Underlined in Table 6 are examples of studies that use more than one methodology and obtain different results for the same country, depending on the methodology applied. In the study developed by Bilgili et al. [146] two methodologies are used, Dynamic Ordinary Least Square (DOLS) and Fully Modified Ordinary Least Square (FMOLS) and 17 Organisation for Economic Co-operation and Development (OECD) countries are analysed. In the individual countries analysis, different results are obtained for Turkey, France and Netherlands. With the FMOLS, a U-shaped relationship was obtained for Turkey, while an inverted U-shaped curve (EKC) was obtained for France and Netherlands. However, with the DOLS, an inverted U-shaped curve (EKC) was obtained for Turkey. In contrast, a U-shaped relationship was obtained for France and the Netherlands.

Another example is the study developed by Destek and Sinha [147]. Two methodologies were used to assess the EKC in the individual countries' analysis, namely FMOLS and Common Correlated Effects (CCE). Through both approaches, FMOLS and CCE, a U-shaped curve relationship was obtained for Austria, Canada, Greece, Italy, Japan, S. Korea, Spain and the US, while an inverted U-shaped curve relationship was revealed for Germany and Turkey. However, for Belgium, Switzerland, Denmark, and the Netherlands, only one of the two methodologies obtained a U-shaped curve relationship. The same for Chile, France, Mexico, New Zealand, Portugal, and the United Kingdom, where only one of the two methodologies obtained an inverted U-shaped curve relationship.

Table 4. Individual analysis.

Authors	Country (ies) and period	Variables analysed on EKC validity	Additional variables included on EKC analysis	Type of analysis and Method(s) employed	Relationship obtained			
					U-shaped	EKC (inverted U-shaped)	N-shaped	inverted N-shaped
[117]	Canada, France, Germany, Italy, Japan, the UK, and the US (1995–2015)	CO_2 emissions –GDP	(i) Renewable EC (ii) International Tourism	(Time series) AMG		√ France		
[87]	Jamaica (1976–2014)	CO_2 emissions –Remittances	–	(Time series) (i) ARDL (ii) NARDL		√		
[53]	Malaysia (1971–2016)	CO_2 emissions –GDP	(i) Globalisation (ii) Industrialization (iii) TO	(Time series) (i) ARDL (ii) VECM		√		
[96]	USA (1980–2016)	(i) EF—Economic Complexity Index (ii) CO_2 emissions—Economic Complexity Index	(i) Non–Renewable EC (ii) Renewable EC (iii) Globalisation	(Time series) (i) FMOLS (ii) DOLS (iii) CCR		√		
[148]	China (1980–2016)	(i) CO_2 emissions –GDP (ii) EF—GDP	(i) Human Capital (ii) Globalization (iii) Renewable EC (iv) TO	(Time series) (i) ARDL (ii) FMOLS (iii) DOLS (iv) CCR	√			
[149]	Algeria, Bahrain, Iran, Kuwait, Oman, Qatar, and Saudi Arabia (1995–2014)	CO_2 emissions—GDP	Electric Power Consumption	(Time series) Multivariate Regression	√ Algeria and Bahrain	√ Oman, Qatar, and Saudi Arabia		
[150]	Manufacturing and Construction Industries of 121 Countries (1960–2014)	(i) CO_2 intensity—GDP (ii) CO_2 emission per capita—GDP (iii) total CO_2 emission—GDP	–	(Time series) OLS		√ 95 of 121 Countries—CO_2 Intensity and CO_2 emission per capita √ 92 of 121 Countries—total CO_2 emissions		
206	Iran, Iraq, and Turkey (1971–2015)	(i) CO_2 emissions—GDP (ii) EF—GDP	(i) Energy Intensity (ii) TO	(Time series) ARDL	√ Iran and Iraq–CO_2	√ Iran, Iraq, and Turkey–EF √ Turkey–CO_2		
201	Colombia (1971–2014)	CO_2 emissions—GDP	(i) Economic Complexity Index (ii) EC (iii) TO (iv) FDI	(Time series) (i) VECM (ii) DOLS (iii) FMOLS (iv) CCR	√ CCR, DOLS	√ FMOLS		

Notes: AMG denotes Augmented Mean Group; ARDL denotes Autoregressive Distributed Lag; CCR denotes Canonical Cointegrating Regression; CO_2 denotes Carbon Dioxide; DOLS denotes Dynamic Ordinary Least Square; EC denotes Energy Consumption; EF denotes Ecological Footprint; FMOLS denotes Fully Modified Ordinary Least Square; GDP Gross Domestic Product; NARDL denotes Nonlinear Autoregressive Distributed Lag; OLS denotes Ordinary Least Square; TO denotes Trade Openness; UK denotes United Kingdom; US denotes United States; VECM denotes Vector Error Correction Model.

3.2.3. Countries sample

The EKC has been assessed for several individual countries (see Table 4) or groups of countries (see Table 5).

However, there is no consensus in the results. The selection of the country (ies), and consequently the cross-sectional or individual analysis performed, directly influences the relationship obtained. According to the literature (see some examples in Table 6), and as identified by Brock and Taylor [43] as the third dilemma of the EKC, heterogeneity makes the EKC results sensitive to the sample. With this in mind, heterogeneity could be one of the main reasons for the difference between the EKC empirical results in cross-country analysis and country-level analysis. Therefore, studies that perform both cross-sectional and individual analyses obtain mixed results. This means when validating the EKC for a group of countries and when analysing each country individually, some countries follow the EKC trajectory, other countries follow a U-shaped relationship, and other countries follow neither a U-shaped nor inverted U-shaped relationship. Table 6 displays various examples of EKC studies that performed both cross-sectional and individual analysis, obtaining different results. Cross-sectional analysis results are in bold in Table 6.

The individual country data analysis assesses the EKC for the environmental condition of a nation, a single economy, throughout time, with increasing income as it develops. Instead of that, cross-country analysis assesses the EKC for the environmental and economic conditions of a group of countries, with distinct stages of development, at a certain moment in time or within a limited time period. Therefore, considering fundamental disparities in national backgrounds and differences in the development paths, a cross-country analysis that reveals an inverted U-shaped pattern does not reveal that each country individually follows the EKC trajectory [158]. In line with this, through the development of the

Green Solow Model, it was concluded that different profiles of income and emissions over time are obtained as a consequence of economies with different initial conditions. EKC profiles are not unique due to the differences in the initial conditions [43]. The EKC estimation is vulnerable to the selection of scale, sample, and range, as well as the spatial and temporal sample range. Therefore, changes could occur in the estimated coefficients, significance levels and variables specification as a consequence of the country or countries under analysis [11].

Table 5. Cross-country analysis.

Authors	Country (ies) and period	Variables analysed on EKC validity	Additional variables included on EKC analysis	Type of analysis and Method(s) employed	Relationship obtained			
					U-shaped	EKC (inverted U-shaped)	N-shaped	inverted N-shaped
[151]	BRICS Countries (1996–2017)	CO_2 emissions—GDP	(i) Governance	(panel) (i) OLS (ii) DOLS (iii) PMG		√		
[152]	71 Countries (1996–2012)	CO_2 emissions—GDP	(i) Urbanization (ii) Industrial Structure (iii) TO (iv) EC Structure (v) Green Patent Counts (vi) Output Gap Ratio	(panel) OLS–FE		√		
[131]	193 Countries (1990–2017)	CO_2 emissions—GDP	(i) EC (ii) FD by Private Sector Credit (iii) TO (iv) Bank FD (v) Population (vi) Merchandise Trade (vii) Infrastructures (viii) Merchandise Trade (ix) Gross Saving (x) Government Expenditure on Educations	(panel) (i) SUR (ii) GMM (iii) 2SGMM (iv) SYS–GMM (v) Sys2Step		√		
[153]	19 of G20 Countries*[13] (1990–2014)	CO_2 emissions—GDP	(i) Agricultural Value Added (ii) Renewable EC	(panel) FMOLS		√ Full sample √ Developed panel		
[54]	France and Germany (1995–2015)	CO_2 emissions –GDP	(i) International Tourism Arrivals (ii) Labour Force (iii) Renewable EC (iv) Non–Renewable EC	(panel) (i) FMOLS (ii) DOLS (iii) VECM-PMG		√		
[89]	20 sub-Saharan African (SSA) countries (1990–2015)	(i) Environmental Degradation Index (EDI)—HDI (ii) EF—HDI	(i) EC (ii) FD (iii) FDI (iv) TO (v) Urbanization (vi) Livestock production	(panel) (i) ARDL (ii) CCE-PMG		√ Global panel—EDI and EF √ Resource-Intensive SSA countries panel–EDI		
[154]	21 developed and developing countries (1990–2016)	CO_2 emissions –GDP	(i) EC (ii) TO (iii) FDI (iv) FD (v) Institutional Framework	(panel) (i) GMM (ii) Sys-GMM		√ Global panel √ Developed Countries panel √ Developing Countries panel		

(continued on next page)

Table 5 (*continued*)

Authors	Country (ies) and period	Variables analysed on EKC validity	Additional variables included on EKC analysis	Type of analysis and Method(s) employed	Relationship obtained			
					U-shaped	EKC (inverted U-shaped)	N-shaped	inverted N-shaped
211	89 Belt and Road Initiative Countries (1995–2017)	(i) CO_2 emissions—GDP	(i) FDI	(panel)	√ Sub-region LA—GLS—CO	√ Full panel—PCSE—all environmental indicators		
		(ii) Sulphur Dioxide (SO_2)—GDP	(ii) Energy Structure		√ Sub-region LA—PCSE—CO_2, VOC, CO	√ Full panel—GLS—CO_2, SO_2, NO_X, CO		
		(iii) Volatile Organic Compounds (VOC)—GDP	(iii) Urbanization	(i) PCSE	√ Sub-region SSA—PCSE—SO_2, VOC, NO_X	√ Sub-region EU—PCSE and GLS—all environmental indicators		
		(iv) Nitrogen Oxides (NO_X)—GDP	(iv) Industrial Structure		√ Sub-region MENA—PCSE—CO_2, SO_2, NO_X	√ Sub-region LA—GLS—SO_2		
		(v) Carbon Monoxide (CO)—GDP		(ii) GLS	√ Sub-region MENA—GLS—SO_2	√ Sub-region AP—PCSE—CO_2, SO_2, NO_X, CO		
						√ Sub-region AP—GLS—SO_2, NO_X		

Notes: ARDL denotes Autoregressive Distributed Lag; BRICS denotes Brazil, Russia, India, China and South Africa; CCE denotes Common Correlated Effects; CO_2 denotes Carbon Dioxide; DOLS denotes Dynamic Ordinary Least Square; EC denotes Energy Consumption; EF denotes Ecological Footprint; FD denotes Financial Development; FE denotes Fixed Effects; FDI denotes Foreign Direct Investment; FMOLS denotes Fully Modified Ordinary Least Square; GDP Gross Domestic Product; GLS denotes Generalized Least Squares; GMM denotes Generalized Method of Moments; HDI denotes Human Development Index; OLS denotes Ordinary Least Square; PMG denotes Pooled Mean Group; SUR denotes Seemingly Unrelated Regression; TO denotes Trade Openness; VECM denotes Vector Error Correction Model.

4. Which are the gaps in the EKC assessment?

With an extensive range of literature, the EKC is a method massively employed to analyse economies' environmental performance. Through the fast growth and development of economies and technology and the increasing complexity of environmental degradation issues, the EKC has started to be employed to analyse not only environmental indicators and not only through simple models. However, an absence of consensus is noted, as well as the degree of sensitivity of the EKC estimation to all the elements that are incorporated into the analysis process. The selection of the indicators, country or countries, time period, methodology and additional variables produce a unique result, and when the EKC is validated, the estimated curve is unlike any other. In light of this, a change of a single component of the functional structure produces changes in the results, validating or not the EKC or changing its shape.

The sensitivity of the EKC function and the consequent change in the results is criticised in some cases. A critical issue raised about the relationship obtained in a panel analysis is that it does not imply that individual countries follow the same pattern (as shown in Table 6). The cross-sectional analysis in EKC studies, mainly performed due to the lack of reliable long-term data [12], analyses a set of economies with different conditions and backgrounds. Taking this into account, the results obtained during a panel analysis should not be directly compared with individual analysis results. Studies that perform a cross-sectional analysis provide results and measures for the specific group of countries under analysis, which may not be the most appropriate for each country in particular. Therefore, to create and apply measures adequate for the characteristics of each economy, the analysis of each country individually or by sector could provide and reveal more specific and beneficial results to the policymakers.

Besides that, EKC estimations are found to be sensitive to the method performed to assess the hypothesis (see Subsection 3.2.2 and Table 6). In other words, the shape obtained is linked to the econometric method chosen and functional specification. Several econometric issues in the EKC modelling have been identified throughout the EKC literature. EKC function and the use of income and squared income variables raised some criticism due to the production of econometric issues. Model emissions as a function of income augmented by income squared and income-cubed raise econometric issues, such as collinearity or multicollinearity [159]. In order to avoid multicollinearity in the estimation, the use of non-parametric or semi-parametric methods should be explored. Besides that, the validity of the EKC hypothesis could be based on the assessment of short- and long-run income elasticities, as stated by Narayan and Narayan [159]. Income elasticities should be interpreted as if the long-run elasticity is less than the short-run elasticity suggesting that the country has reduced its emissions with income growth and consequently further proving the existence of the EKC [119, 159].

Besides multicollinearity, there are more econometric issues associated with the modelling of the EKC. Hasanov et al. [160] extensively identify the major econometric issues in the EKC literature and provide a full mathematically and empirically explanation for each one. The authors mainly focused on the following issues: functional specifications used, and the econometric techniques employed; the use of a trend in the specification and level versus logarithmic variables; and the monotonic, quadratic, cubic, and quartic potential relationship between income and environmental degradation. In light of this, the authors developed a modelling strategy that should ensure a consistent approach when assessing the EKC. The Green Solow Model might be useful to overcome the sensitivity of the EKC to the econometric models employed.

Besides the critical issues identified in the EKC assessment and strategies to overcome them, from the extensive EKC literature arises the challenge: what are the EKC assessment gaps? Throughout the EKC literature, it has been noted that essential components for environmental degradation may not have been taken into consideration, such as consumption instead of production and technological progress. A criticism made of the EKC arises because it does not take into account the evolution of consumption coinciding with economic growth. That is, the EKC only explains how the process of production is converted into something environmentally friendly as a consequence of economic growth [10]. Besides, according to Kaika and Zervas [161], the EKC only focuses on domestic production and overlooks the impact of the consumption of imported goods on the environment. In turn, the income elasticity of demand for dirty goods has been disregarded by the EKC [40]. If, with high income levels, the demand for dirty goods persists, then this situation will lead to developed countries importing these goods from developing economies to satisfy demand. Consequently, any environmental improvement resulting from technological progress will be offset, and economic growth will result in more environmental degradation.

This is a critical issue that goes against one of the basic assumptions of the EKC, that is, that there is a change in consumer behaviour with a rise in income.

Technological progress is a crucial tool to help with climate change and global warming mitigation. EKC supporters believe that environmental mitigation depends on technological progress and improvement. Therefore, they believe that only if technology and investment in the environment persist stagnantly, then the enlargement of economic activities harms the environment. However, the fact that technology enhances environmental quality is an ambition in dynamic economies, making economic growth a tool to accomplish environmental quality instead of being a threat [10]. The EKC hypothesis assumes that rising

Table 6. Individual vs cross-country analysis.

Authors	Country (ies) and period	Variables analysed on EKC validity	Additional variables included on EKC analysis	Type of analysis and Method(s) employed	Relationship obtained			
					U-shaped	EKC (inverted U-shaped)	N-shaped	inverted N-shaped
[155]	Sub Saharan African Countries (1980–2012)	CO_2 emissions–GDP	Energy Intensity	(Time series and panel)	√ Senegal, Nigeria and Cameroon	√ South Africa, Congo Republic, Ethiopia and Togo		
				(i) VECM (ii) Johansen Maximum Likelihood		(ii) **panel**		
[146]	17 OECD Countries (1977–2010)	CO_2 emissions–GDP	Renewable Energy Consumption	(Time series and panel)	√ FMOLS: Austria, Canada, Turkey	√ **panel**		
				(i) FMOLS	√ DOLS: France, Luxemburg, Netherlands, Norway	√ FMOLS: Denmark, France, Greece, Netherlands, Sweden		
				(ii) DOLS		(iii) DOLS: Australia, Belgium, Greece, New Zealand, Portugal, Turkey		
[156]	11 Central and Eastern European Countries (1996–2015)	(i) CO_2 emissions—GDP	(i) Gross Inland Energy Consumption	(Panel and time series)	√ CO_2 emissions—Bulgaria and Latvia	√ CO_2 emissions—Czech R. and Hungary	√ CO_2 emissions, Biocapacity and SO_2 emissions–**panel**	√ CO_2 emissions—Poland and Slovakia
		(ii) Biocapacity—GDP	(ii) Index of Economic Freedom of Heritage Foundation	(i) MG			√ CO_2 emissions—Croatia and Estonia	
		(iii) EF—GDP	(iii) Globalisation	(ii) MG-FMOLS				
		(iv) SO_2 emissions-GDP	(iv) FDI	(iii) AMG				
			(v) Labour Productivity					
			(vi) Economic Complexity Index					
			(vii) HDI					
			(viii) Sectoral Structure of Agriculture, industry, and Services					
[157]	11 newly industrialized Countries (1977–2013)	EF–GDP	(i) Energy Consumption	(Time series and panel)	√ China, India, South Korea, Thailand, and Turkey	√ Mexico, Philippines, Singapore, and South Africa		
			(ii) Financial Development	AMG		√ **panel**		
[55]	10 electricity consuming Countries (1971–2013)	CO_2 emissions -GDP	(i) Electricity Consumption	(Panel)	√ China, USA and UK	√ **Panel**		
			(ii) KOF Globalisation Index	(i) FMOLS		√ Japan, Germany and S. Korea		
				(ii) DOLS				
				(Time series)				
				FMOLS				

(continued on next page)

Table 6 (*continued*)

Authors	Country (ies) and period	Variables analysed on EKC validity	Additional variables included on EKC analysis	Type of analysis and Method(s) employed	Relationship obtained			
					U-shaped	EKC (inverted U-shaped)	N-shaped	inverted N-shaped
[147]	24 OECD countries (1980–2014)	Ecological Footprint–GDP	(i) Renewable Energy Consumption	(Panel)	√ MG, FMOLS-MG and DOLS-MG: **panel**	√ CCE: Germany; Turkey		
			(ii) Non-Renewable Energy Consumption	(i) MG	√ CCE: Austria; Belgium; Canada; Greece; Italy; Japan; S. Korea; Spain; Switzerland; US	√ FMOLS: Chile; France; Germany; Mexico; New Zealand; Portugal; Turkey; UK		
			(iii) Trade Openness	(ii) FMOLS-MG				
				(iii) DOLS-MG				
				(iv) CCE-MG(Time series)	√ FMOLS: Austria; Canada; Denmark; Greece; Italy; Japan; S. Korea; Netherlands; Spain; US			
				(i) FMOLS				
				(ii) CCE				
199	South Asian Economies*[3] (1985–2018)	CO_2 emissions—GDP	(i) Globalization	(Time series and panel)		√ Full panel		
			(ii) Non-Renewable Energy Consumption	FMOLS		√ Bangladesh, India, Sri Lanka, and Nepal		

Notes: AMG denotes Augmented Mean Group; CCE denotes Common Correlated Effects; CO_2 denotes Carbon Dioxide; DOLS denotes Dynamic Ordinary Least Square; EF denotes Ecological Footprint; FDI denotes Foreign Direct Investment; FMOLS denotes Fully Modified Ordinary Least Square; GDP Gross Domestic Product; HDI denotes Human Development Index; MG denotes Mean Group; OECD denotes Organisation for Economic Co-operation and Development; SO_2 denotes Sulphur dioxide; UK denotes United Kingdom; US denotes United States; USA denotes United States of America; VECM denotes Vector Error Correction Model.

income induces technological improvements and environmental awareness, and consequently, it should safeguard the improvement of environmental performance in the later stages of economic growth. At this point surfaces the doubt if technological advancements can outrun the worrying pace of environmental damage. Gill, Viswanathan and Hassan [10] present a summary of examples of recent technological improvements in diverse sectors. Therefore it is crucial to include technological progress in the EKC assessment. Currently, technological progress is focused on environmental research, and technological progress indexes have been developed [162, 163]. Also, the Green Solow Model could be a valuable tool to analyse technological improvements as it incorporates technological progress and resorts to enunciating the two conditions needed to guarantee sustainable growth.

Technological improvement encourages the replacement of obsolete technology and drives intensive pollutant economies to efficient ones. These changes mean that economies that reduce their energy consumption per unit of economic output consequently reduce emissions. The level of technology is vastly different in developing economies compared with developed, and therefore the developing economies are more carbon-intensive. According to Beckerman [15], only prosperous economies have the means to access environmentally friendly technologies in order to mitigate environmental degradation, while the poor economies, according to the author, are "too poor to be green". However, when a developed or prosperous economy appears to be able to achieve economic growth without significant environmental impact, then it is necessary to look deeper into the location of that economy's pollutant industries. Developing economies' lax environmental regulations attract the relocation of pollutant industries from developed economies where there is pressure to accomplish environmental targets.

The relocation of pollutant industries separates production from consumption, which allows an increase in GDP with a reduction in emissions as the emissions are being emitted in another country. Therefore, the relocation of emissions-intensive industries could create an illusion that economies are becoming efficient and that they perform the EKC trajectory, and it deserves to be taken into consideration in the analysis of environmental performance. The analysis of technological progress (or energy efficiency index) could be useful in order to observe if any emissions reduction actually comes from the replacement with efficient technology or if their emissions are reducing through the relocation of their pollutant industries. A sectoral analysis or a joint analysis of the home with the host country (the country that receives the industry) could overcome the illusion of emissions reduction when they are just being relocated. A sectoral analysis could reveal from which sector the industries were relocated. In turn, an analysis of the home and host country could reveal the reduction of emissions in the home country that consequently represents an increase in the emissions of the host country.

Nevertheless, in order to achieve a significant reduction in environmental problems and produce more economic growth with less environmental damage, the technology improvements have to be huge. Considering that energy consumption is the main source of emissions, energy efficiency through efficient technology may not be enough to achieve meaningful emissions reduction. In light of this, the studies should focus on how economic growth can promote energy transition from fossil energy use to renewable energy use. Energy transition is currently a hot topic due to the global environmental agenda, and throughout the literature, energy transition indicators have been rising in importance [164, 165]. It is critical to be concerned about the shortcoming of the storage of renewable energy sources. Scenarios with nuclear may be analysed as an intermediate process, but they must take into account the risks associated with this energy source. Producing more economic growth with less environmental damage is crucial to accomplishing the Sustainable Development Goals, also known as Agenda 2030. Global economic growth patterns are considered responsible for the issue of rising climatic disasters across the globe [166], and reducing global emissions and moving toward decarbonization is urgent. However, sustainable development goals accomplishment requires large investment needs. The COP26 was focused on tools to reduce climate change issues, such as green and climate finance. Green and climate finance could be powerful tools to bring about adaptation and mitigation of climate change issues mainly in countries with capital in short supply and could have a meaningful influence on the assessment of the EKC path. Green finance and climate finance have recently started to be addressed in the literature about the environment [167, 168].

As the doubt if technological progress can slow down and reverse the pace of environmental damage grows, there is also the increasing uncertainty of what will happen to the environmental degradation already in place. Is it repairable? According to the EKC relationship, after achieving a certain level of income, the turning point, environmental degradation starts to decrease with growing income. However, can the later stages of economic development really repair the environmental damage of the first stages? The EKC hypothesis assumes that in the later stages of economic growth, the environmental damage as a consequence of economic growth can be reversed. However, this assumption is an object of criticism by various researchers. The ability to reverse environmental damage might be effective for specific air and water pollutants but might not work with things like carcinogenic chemicals, as they are considered irreparable [24]. Furthermore, environmental damage because of industrialization is also extraordinarily complex to overturn.

Global warming is considered the most critical environmental problem humanity has ever faced. Therefore, it is crucial to understand if the environmental damage provoked by economic growth can be repaired through more economic growth. At the moment, it is not enough to only analyse if the country or a group of countries perform the EKC trajectory. It is now necessary to start exploring how the environmental damage provoked in the first phase of the EKC can be repaired. In line with this, also arises the doubt if the growth path traced by the inverted U-shaped is efficient, a Pareto efficient. The Pareto efficient, or optimal, defines the optimum resource allocation at which it is not possible to reallocate in order to benefit or improve a specific resource allocation without harming the allocation of others. The EKC hypothesis transmits the message of ‘grow now and clean later’ [10]. This growth strategy is highly intensive in resources, which makes it incompatible with being Pareto efficient.

Considering that the EKC is not Pareto efficient and that the growth path is highly resource-intensive, it is highly likely that the environmental damage provoked in the first phases of the EKC might not be repairable. A growth path that takes care of both economic development and the environment simultaneously could avoid substantial losses, avoid the huge environmental impact of economic development, and the percentage of economic growth that in the future will be necessary to repair the environmental damage provoked before. On the one hand, a growth path that takes care of the environment in the early stages of economic growth could represent a global GDP loss of 1%. On the other hand, a loss in order of 5–20% of global GDP is a consequence of the absence of environmental care [169]. Therefore, environmental protection throughout all the stages of economic development could diminish environmental and GDP losses.

5. Conclusion

Motivated by the will to develop a useful EKC's research tool/guide that allows EKC researchers to learn from the origins and framework of the EKC until the evolution of the literature, gaps, econometric issues, and improvements needs, this present paper fulfils a gap in the EKC literature by providing a detailed and comprehensive description of the EKC framework, an extensive contextualization of the EKC evolution and literature, and a critical analysis. With various novelty aspects, this research strives to enlarge the knowledge of the EKC field. The main contribution of this review article consists of providing an extremely detailed description of the literature and evolution of the EKC analysis. Through the analysis of more than 200 articles from 1998 to 2022, a considerable number of EKC relationships analysed in the literature are provided, along with additional variables included in EKC estimations and methodologies used. Furthermore, each detail of the EKC assessment for each one of the more than 200 articles supplied allows researchers to find specific information to support their analysis.

The knowledge and assessment of the EKC has developed noticeably since its inception. However, despite being broadly assessed within the vast literature, the EKC hypothesis possesses some gaps and econometric issues, and improvement needs are verified. The absence of consensus throughout the EKC literature on the existence and shape of the curve has given rise to doubts about econometric issues in EKC modelling. The same geographic region, country or countries can generate opposing arguments regarding the existence and shape of the EKC. Throughout the literature review, evidence has been provided regarding the sensitivity of the EKC estimation resulting from the data set used, the indicators, the type of analysis (time series or cross-sectional), the methodology applied, and additional variables included. In light of this, the econometric issues are mainly associated with the functional specifications and econometric techniques used and the use of income quadratic, cubic and quartic variables. The use of econometric methods which deal with collinearity and multicollinearity is crucial. Non- or semi-parametric methods assessing short- and long-run elasticities could avoid these phenomena. Also, non-econometric methods instead of econometric could be helpful to avoid EKC sensitivity to the approach used.

Besides improvements needed for the econometric procedure, further improvements should be made to fill gaps in the EKC analysis. Knowledge of the EKC needs to be improved by integrating insights from other disciplines and research areas. These could include the inclusion of certain socio-political indicators that can influence efforts to improve environmental quality, such as research and development of alternative energy sources; economic complexity; economic uncertainty; economic, cultural, and political shocks; corruption; and political cooperation. All of these would be beneficial for economic analysis and policy recommendations. The complexity of environmental degradation issues is increasing, and scenarios such as relocated pollution, delocalized production, energy and production goods countries' dependence, lax environmental regulation, and comparative advantages, among others, can influence the environmental performance of countries. The relocation of pollutant industries could produce a result that does not fit with reality. The relocation that comes from lax environmental regulation from the host country, comparative advantages from home countries over the host ones that result in relocated pollution, delocalized production, and a countries’ dependence increases environmental degradation in the host countries while the goods produced are consumed in the home country. At this point, it is crucial to consider these scenarios during the EKC assessment in order to allow policymakers to develop and implement fair and effective policies conducive to the achievement of the sustainable development goals. Furthermore, policies should be developed in order to dissolve the strong disparity in environmental regulation between developed and developing countries, allowing an EKC analysis to be more reliable.

COP 26, five years apart from the Paris agreement, was the time for countries to strengthen their environmental commitment and goals. Achieving decarbonisation is urgent and requires the collaboration of all countries all over the world. In light of this, as widely implemented to assess environmental performance, the EKC assessment should be demanding. Analysing environmental degradation indicators or other indicators over the economic growth is not enough at this point; it is crucial to look further into environmental pollution indicators. The standard approach to global warming, which mainly consists of alleviating the restrictions on economic growth while supporting continuous technological development thought suitable to compensate for environmental damage, may be critical. A set of strategies and tools have been developed, and they should be included in the assessment of the path of environmental pollution over economic development. Technological progress, energy efficiency, energy transition, potential clean energy sources (such as nuclear), environmental regulation, and green and climate finance can influence this path and provide a realistic route to a cleaner environment. In light of this, the inclusion of these tools and drivers of environmental quality in the EKC analysis may allow policymakers to develop particular policies and measures in order to encourage their progress and improvement towards sustainability. A major concern of environmental mitigation is the economic growth path; however, achieving sustainable and low-carbon development may, under reasonable conditions, operate as an explicit contributing component to growth.

The eminent consequences of global warming place policymakers as central players in the current global discussion of climate change challenges. The EKC is extensively used to evaluate the environmental performance of economies, and several policy recommendations have already been proposed based on its analysis. However, policymakers must be aware of the high volatility and sensitivity of the EKC outcomes. Panel data analysis could produce strong limitations for the development of policies. Specific policies should not be designed for a particular country based on a panel data analysis where the country is inserted when it is not mandatory that the country follows the trajectory that the group follows as a whole. Therefore, the outcomes of the panel data analysis should only be considered as a reference for how those countries behave together under the same conditions and in a specific scenario. Considering the sensitivity of the EKC outcomes, the EKC might be considered as an environmental performance indicator on policy design and implementation, but as a reference and not as a decisive indicator by itself.

The present study provides a comprehensive and detailed picture of the EKC field. The development of this study faced some limitations, which are necessary to be highlighted to improve future research. Each EKC shape obtained is unique, considering things such as the functional specification, econometric methods used, and sample. Consequently, with a very extensive literature on the field, a huge limitation was faced in identifying all the issues related to the EKC assessment, mainly econometric issues. Moreover, developing a review article, mainly a particularly detailed one, is unending research, considering the tremendous amount of research on the field and that it is constantly growing. At this point, the length of the article could be a limitation. For the future direction of research, it could be relevant to explore methods beyond econometric methods that could fulfil the EKC assessment and overcome the identified econometric issues. Also, it could be useful to further investigate the influence of the additional variables on the EKC assessment. Additionally, providing individual reports about each strand of the Kuznets curve, beyond the Environmental, could be a relevant contribution to the literature.

Declarations

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Funding statement

Professor António Cardoso Marques and Patrícia Hipólito Leal were supported by Fundação para a Ciência e a Tecnologia [UIBD/04630/2020 & DFA/BD/6026/2020].

Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare the following conflict of interests: The author António Cardoso Marques is Associate Editor of Heliyon - Energy Section.

Additional information

Supplementary content related to this article has been published online at https://doi.org/10.1016/j.heliyon.2022.e11521.

References

[1] IAE, Global Energy Review: CO2 Emissions in 2020, 2021. https://www.iea.org/articles/global-energy-review-co2-emissions-in-2020.
[2] WWF, Living Planet Report 2014: Species and Spaces, People and Places, WWF, Gland, Switzerland, 2014.
[3] H. Mahmood, Consumption and territory based CO2 emissions, renewable energy consumption, exports and imports nexus in South America: spatial analyses, Pol. J. Environ. Stud. 31 (2022) 1183–1191.
[4] S.A. Sarkodie, I. Ozturk, Investigating the environmental kuznets curve hypothesis in Kenya: a multivariate analysis, Renew. Sustain. Energy Rev. 117 (2020), 109481.
[5] (WCED) World Commission on Environment and Development, Our Common Future, Oxford University Press, Oxford, 1987.
[6] H. Meadows, D.,L. Meadows, D.,J. Randers, W. Behrens, The Limits to Growth, Universe Books, New York, 1972.
[7] P. Holdren, J.,R. Ehrlich, Human population and the global environment, Am. Sci. 62 (1974) 282–292.
[8] S. Kuznets, Economic growth and income inequality, Am. Econ. Rev. 45 (1955) 1–28.
[9] G.M. Grossman, A.B. Krueger, Environmental impacts of a north American free trade agreement, Natl. Bur. Econ. Res. Work. Pap. Ser. No. 3914 (1991) 1–57.
[10] A. Rashid Gill, K.K. Viswanathan, S. Hassan, The Environmental Kuznets Curve (EKC) and the environmental problem of the day, Renew. Sustain. Energy Rev. 81 (2018) 1636–1642.
[11] N. Shafik, S. Bandyopadhyay, Economic growth and environmental quality: time series and cross-country evidence, Policy Res. Work. Pap. Ser. 18 (1992) 55.
[12] R. Roy Chowdhury, E.F. Moran, Turning the curve: a critical review of Kuznets approaches, Appl. Geogr. 32 (2012) 3–11.
[13] T. Panayotou, Empirical tests and policy analysis of environmental degradation at different stages of economic development, Technol. Environ. Employ. Geneva Int. Labour Off. World Empl (1993) 13–36.
[14] D. Holtz-Eakin, T. Selden, Stoking the fires? CO 2 emissions and economic growth, J. Publ. Econ. 57 (1995) 85–101.
[15] W. Beckerman, Economic growth and the environment: whose growth? whose environment? World Dev. 20 (1992) 481–496.
[16] P. Ekins, Limits to growth" and "sustainable development": grappling with ecological realities, Ecol. Econ. 8 (1993) 269–288.
[17] World Bank, World Development Report, Development and the Environment, 1992. http://documents.worldbank.org/curated/en/995041468323374213/pdf/105170REPLACEMENT0WDR01992.pdf.
[18] S. Dinda, Environmental kuznets curve hypothesis: a survey, Ecol. Econ. 49 (2004) 431–455.
[19] D.I. Stern, The rise and fall of the environmental kuznets curve, World Dev. 32 (2004) 1419–1439.
[20] D. Kaika, E. Zervas, The Environmental Kuznets Curve (EKC) theory-Part A: concept, causes and the CO2 emissions case, Energy Pol. 62 (2013) 1392–1402.
[21] D. Kwabena Twerefou, K. Danso-Mensah, G.A. Bokpin, The environmental effects of economic growth and globalization in Sub-Saharan Africa: a panel general method of moments approach, Res. Int. Bus. Finance 42 (2017) 939–949.
[22] E. Olale, T.O. Ochuodho, V. Lantz, J. El Armali, The environmental Kuznets curve model for greenhouse gas emissions in Canada, J. Clean. Prod. 184 (2018) 859–868.
[23] S.A. Sarkodie, V. Strezov, Assessment of contribution of Australia's energy production to CO2 emissions and environmental degradation using statistical dynamic approach, Sci. Total Environ. 639 (2018) 888–899.
[24] S. Dasgupta, B. Laplante, H. Wang, D. Wheeler, Confronting the environmental Kuznets curve, J. Econ. Perspect. 16 (2002) 147–168.
[25] S.A. Sarkodie, V. Strezov, A review on Environmental Kuznets Curve hypothesis using bibliometric and meta-analysis, Sci. Total Environ. 649 (2019) 128–145.
[26] D.I. Stern, Environmental kuznets curve, Encycl. Energy. 2 (2004) 517–525.
[27] B. Yandle, M. Vijayaraghavan, M. Bhattarai, The environmental Kuznets curve, A Prim. PERC Res. Study. (2002) 1–2.
[28] S.P.A. Brown, I.K. McDonough, Using the Environmental Kuznets Curve to evaluate energy policy: some practical considerations, Energy Pol. 98 (2016) 453–458.
[29] S. Bimonte, A. Stabile, EKC and the income elasticity hypothesis Land for housing or land for future? Ecol. Indic. 73 (2017) 800–808.
[30] T. Panayotou, Demystifying the environmental Kuznets curve: turning a black box into a policy tool, Environ. Dev. Econ. 2 (1997) 465–484.
[31] R. López, S. Mitra, Corruption, pollution, and the Kuznets environment curve, J. Environ. Econ. Manage. 40 (2000) 137–150.
[32] M. Torras, J.K. Boyce, Income, inequality, and pollution: a reassessment of the environmental Kuznets curve, Ecol. Econ. 25 (1998) 147–160.
[33] E. Magnani, The Environmental Kuznets Curve, environmental protection policy and income distribution, Ecol. Econ. 32 (2000) 431–443.
[34] S. Bimonte, Information access, income distribution, and the environmental kuznets curve, Ecol. Econ. 41 (2002) 145–156.

[35] A. Acaravci, I. Ozturk, On the relationship between energy consumption, CO2 emissions and economic growth in Europe, Energy 35 (2010) 5412–5420.
[36] R. Baldwin, Does sustainability require growth? in: I. Goldin, L.A. Winters (Eds.), Econ. Sustain. Dev. Cambridge University Press, 1995, pp. 51–78.
[37] B. Girod, D.P. van Vuuren, E.G. Hertwich, Climate policy through changing consumption choices: options and obstacles for reducing greenhouse gas emissions, Glob. Environ. Chang. 25 (2014) 5–15.
[38] T.M. Selden, D. Song, Environmental quality and development: is there a kuznets curve for air pollution emissions? J. Environ. Econ. Manage. 27 (1994) 147–162.
[39] V. Suri, D. Chapman, Economic growth , trade and energy : implications for the environmental Kuznets curve 25, 1998, pp. 195–208.
[40] M.A. Cole, Trade , the pollution haven hypothesis and the environmental Kuznets curve : examining the linkages 48, 2004, pp. 71–81.
[41] A. Kearsley, M. Riddel, A further inquiry into the pollution haven hypothesis and the environmental kuznets curve, Ecol. Econ. 69 (2010) 905–919.
[42] S.A. Sarkodie, V. Strezov, Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries, Sci. Total Environ. 646 (2019) 862–871.
[43] W.A. Brock, M.S. Taylor, The green Solow model, J. Econ. Growth. 15 (2010) 127–153.
[44] R.M. Solow, A contribution to the theory of economic growth, Q. J. Econ. 70 (1956) 65–94.
[45] R. Vogan, Pollution abatement and control expenditures: 1972–1994, Surv, Curr. Bus. 76 (1996) 48–67. https://faq.bea.gov/scb/pdf/national/niparel/1996/0996eed.pdf.
[46] N. Stokey, Are there limits to growth? Int. Econ. Rev. (Philadelphia) 39 (1998) 1–31. https://econpapers.repec.org/RePEc:ier:iecrev:v:39:y.
[47] V. Moutinho, C. Varum, M. Madaleno, How economic growth affects emissions? An investigation of the environmental Kuznets curve in Portuguese and Spanish economic activity sectors, Energy Policy 106 (2017) 326–344.
[48] Z. Mrabet, M. Alsamara, Testing the Kuznets Curve hypothesis for Qatar: a comparison between carbon dioxide and ecological footprint, Renew. Sustain. Energy Rev. 70 (2017) 1366–1375.
[49] A. Kacprzyk, Z. Kuchta, Shining a new light on the environmental kuznets curve for co2 emissions, Energy Econ (2020), 104704.
[50] E.M. Mosconi, A. Colantoni, F. Gambella, E. Cudlinová, L. Salvati, J. Rodrigo-Comino, Revisiting the environmental kuznets curve: the spatial interaction between economy and territory, Economies 8 (2020).
[51] M. Saqib, F. Benhmad, Updated meta-analysis of environmental Kuznets curve: where do we stand? Environ. Impact Assess. Rev. 86 (2021), 106503.
[52] M. Anwar, Q. Zhang, F. Asmi, N. Hussain, A. Plantinga, M. Wasif, A. Sinha, Global perspectives on environmental kuznets curve : a bibliometric review, Gondwana Res 103 (2022) 135–145.
[53] B. Aslam, J. Hu, M. Hafeez, D. Ma, T.S. AlGarni, M. Saeed, M.A. Abdullah, S. Hussain, Applying environmental Kuznets curve framework to assess the nexus of industry, globalization, and CO2 emission, Environ. Technol. Innov. 21 (2021), 101377.
[54] X. Ma, N. Ahmad, P.-Y. Oei, Environmental Kuznets curve in France and Germany: role of renewable and nonrenewable energy, Renew. Energy. 172 (2021) 88–99.
[55] M.M. Rahman, Environmental degradation: the role of electricity consumption, economic growth and globalisation, J. Environ. Manage. 253 (2020), 109742.
[56] D.H. Kim, Y.B. Suen, S.C. Lin, Carbon dioxide emissions and trade: evidence from disaggregate trade data, Energy Econ 78 (2019) 13–28.
[57] E. Akalpler, S. Hove, Carbon emissions , energy use , real GDP per capita and trade matrix in the Indian economy-an ARDL approach, Energy 168 (2019) 1081–1093.
[58] W. Adzawla, M. Sawaneh, A.M. Yusuf, Greenhouse gasses emission and economic growth nexus of sub-Saharan Africa, Sci. African. 3 (2019).
[59] C. Aydin, Ö. Esen, R. Aydin, Is the ecological footprint related to the Kuznets curve a real process or rationalizing the ecological consequences of the affluence? Evidence from PSTR approach, Ecol. Indic. 98 (2019) 543–555.
[60] J. Andreoni, A. Levinson, The simple analytics of the EKC, J. Public Econ. 80 (2001) 269–286. http://ac.els-cdn.com/S0047272700001109/1-s2.0-S0047272700001109-main.pdf?_tid=2800f2de-c179-11e2-bcef-00000aab0f27&acdnat=1369073868_172b9745b5e519cb75de0cd05008aab7.
[61] M.S. Alam, S.R. Paramati, The impact of tourism on income inequality in developing economies: does Kuznets curve hypothesis exist? Ann. Tour. Res. 61 (2016) 111–126.
[62] U.K. Pata, D. Balsalobre-Lorente, Exploring the impact of tourism and energy consumption on the load capacity factor in Turkey: a novel dynamic ARDL approach, Environ. Sci. Pollut. Res. 29 (2022) 13491–13503.
[63] S. Gui, L. Zhao, Z. Zhang, Does municipal solid waste generation in China support the Environmental Kuznets Curve? New evidence from spatial linkage analysis, Waste Manag 84 (2019) 310–319.
[64] Y. Hao, Y. Xu, J. Zhang, X. Hu, J. Huang, C.P. Chang, Y. Guo, Relationship between forest resources and economic growth: empirical evidence from China, J. Clean. Prod. 214 (2019) 848–859.
[65] H. Mahmood, T.T.Y. Alkhateeb, M. Tanveer, D.H.I. Mahmoud, Testing the energy-environmental kuznets curve hypothesis in the renewable and nonrenewable energy consumption models in Egypt, Int. J. Environ. Res. Public Health. 18 (2021).
[66] H. Mahmood, The spatial analyses of consumption-based CO2 emissions, exports, imports, and FDI nexus in GCC countries, Environ. Sci. Pollut. Res. 29 (2022) 48301–48311.
[67] J. Zhao, Z. Zhao, H. Zhang, The impact of growth, energy and financial development on environmental pollution in china: new evidence from a spatial econometric analysis, Energy Econ (2019), 104506.
[68] M.D.P. Pablo-Romero, J. De Jesús, Economic growth and energy consumption: the energy-environmental kuznets curve for Latin America and the caribbean, Renew. Sustain. Energy Rev. 60 (2016) 1343–1350.
[69] R. Kurniawan, S. Managi, Coal consumption, urbanization, and trade openness linkage in Indonesia, Energy Policy 121 (2018) 576–583.
[70] S. Chen, Y. Zhang, Y. Zhang, Z. Liu, The relationship between industrial restructuring and China's regional haze pollution: a spatial spillover perspective, J. Clean. Prod. 239 (2019), 115808.
[71] K.H. Nguyen, M. Kakinaka, Renewable energy consumption, carbon emissions, and development stages: some evidence from panel cointegration analysis, Renew. Energy. 132 (2019) 1049–1057.
[72] Y. Hao, X. Hu, H. Chen, On the relationship between water use and economic growth in China : New evidence from simultaneous equation model analysis, J. Clean. Prod. 235 (2019) 953–965.
[73] Y. Ding, M. Zhang, S. Chen, W. Wang, R. Nie, The environmental Kuznets curve for PM 2.5 pollution in Beijing-Tianjin-Hebei region of China: a spatial panel data approach, J. Clean. Prod. 220 (2019) 984–994.
[74] F. Pothen, H. Welsch, Economic development and material use. Evidence from international panel data, World Dev 115 (2019) 107–119.
[75] A.A. Haug, M. Ucal, The role of trade and FDI for CO 2 emissions in Turkey: Nonlinear relationships, Energy Econ 81 (2019) 297–307.
[76] P.D. Hien, Excessive electricity intensity of Vietnam: evidence from a comparative study of Asia-Pacific countries, Energy Policy 130 (2019) 409–417.
[77] L. Miao, H. Gu, X. Zhang, W. Zhen, M. Wang, Factors causing regional differences in China's residential CO 2 emissions—evidence from provincial data, J. Clean. Prod. 224 (2019) 852–863.
[78] J.M. Dyrstad, A. Skonhoft, M.Q. Christensen, E.T. Odegaard, Does economic growth eat up environmental improvements? Electricity production and fossil fuel emission in OECD countries 1980–2014, Energy Policy 125 (2019) 103–109.
[79] L. Zhang, J. Pang, X. Chen, Z. Lu, Carbon emissions, energy consumption and economic growth: evidence from the agricultural sector of China's main grain-producing areas, Sci. Total Environ. 665 (2019) 1017–1025.
[80] U. Deichmann, A. Reuter, S. Vollmer, F. Zhang, The relationship between energy intensity and economic growth : New evidence from a multi-country multi-sectorial dataset, World Dev 124 (2019), 104664.
[81] W. Liang, M. Yang, Urbanization, economic growth and environmental pollution: evidence from China, Sustain. Comput. Informatics Syst. 21 (2019) 1–9.
[82] D. Borozan, Unveiling the heterogeneous effect of energy taxes and income on residential energy consumption, Energy Policy 129 (2019) 13–22.
[83] Q. Chen, D. Taylor, Economic development and pollution emissions in Singapore: evidence in support of the Environmental Kuznets Curve hypothesis and its implications for regional sustainability, J. Clean. Prod. 243 (2020), 118637.
[84] A. Kibria, S.B. Akhundjanov, R. Oladi, Fossil fuel share in the energy mix and economic growth, Int. Rev. Econ. Financ. 59 (2019) 253–264.
[85] G.N. Ike, O. Usman, S.A. Sarkodie, Fiscal policy and CO2 emissions from heterogeneous fuel sources in Thailand: evidence from multiple structural breaks cointegration test, Sci. Total Environ. 702 (2020), 134711.
[86] A.R. Germani, A.P. Ker, A. Castaldo, On the existence and shape of an environmental crime Kuznets Curve: a case study of Italian provinces, Ecol. Indic. 108 (2020), 105685.
[87] L. Brown, A. McFarlane, K. Campbell, A. Das, Remittances and CO2 emissions in Jamaica: an asymmetric modified environmental kuznets curve, J. Econ. Asymmetries. 22 (2020), e00166.
[88] C. Xu, Z. Yiwen, B. Cheng, L. Li, M. Zhang, Study on environmental Kuznets Curve for noise pollution: a case of 111 Chinese cities, Sustain. Cities Soc. 63 (2020), 102493.
[89] D. Tenaw, A.D. Beyene, Environmental sustainability and economic development in sub-Saharan Africa: a modified EKC hypothesis, Renew. Sustain. Energy Rev. 143 (2021), 110897.
[90] B. Boubellouta, S. Kusch-Brandt, Testing the environmental Kuznets Curve hypothesis for E-waste in the EU28+2 countries, J. Clean. Prod. 277 (2020), 123371.
[91] W. Li, Y. Qiao, X. Li, Y. Wang, Energy consumption, pollution haven hypothesis, and Environmental Kuznets Curve: examining the environment–economy link in belt and road initiative countries, Energy 239 (2022), 122559.
[92] S.A.R. Khan, K. Zaman, Y. Zhang, The relationship between energy-resource depletion, climate change, health resources and the environmental Kuznets curve: evidence from the panel of selected developed countries, Renew. Sustain. Energy Rev. 62 (2016) 468–477.
[93] A. Sheikhzeinoddin, M.H. Tarazkar, A. Behjat, U. Al-mulali, I. Ozturk, The nexus between environmental performance and economic growth: New evidence from the Middle East and North Africa region, J. Clean. Prod. 331 (2022), 129892.
[94] H. Altıntaş, Y. Kassouri, Is the environmental Kuznets Curve in Europe related to the per-capita ecological footprint or CO2 emissions? Ecol. Indic. 113 (2020).
[95] L. Liu, Environmental poverty , a decomposed environmental Kuznets curve , and alternatives : sustainability lessons from China, Ecol. Econ. 73 (2012) 86–92.
[96] U.K. Pata, Renewable and non-renewable energy consumption, economic complexity, CO2 emissions, and ecological footprint in the USA: testing the EKC hypothesis with a structural break, Environ. Sci. Pollut. Res. 28 (2021) 846–861.
[97] D. Balsalobre-Lorente, O.M. Driha, N.C. Leitão, M. Murshed, The carbon dioxide neutralizing effect of energy innovation on international tourism in EU-5 countries under the prism of the EKC hypothesis, J. Environ. Manage. 298 (2021).
[98] E. Abokyi, P. Appiah-Konadu, K.F. Tangato, F. Abokyi, Electricity consumption and carbon dioxide emissions: the role of trade openness and manufacturing sub-sector output in Ghana, Energy Clim. Chang. 2 (2021), 100026.

[99] H. Mahmood, M. Furqan, Oil rents and greenhouse gas emissions: spatial analysis of Gulf Cooperation Council countries, Environ. Dev. Sustain. 23 (2021) 6215–6233.
[100] R.K. Kaufmann, B. Davidsdottir, S. Garnham, P. Pauly, The determinants of atmospheric SO2 concentrations: reconsidering the environmental Kuznets curve, Ecol. Econ. 25 (1998) 209–220.
[101] J.V.A. Itkonen, Problems estimating the carbon Kuznets curve, Energy 39 (2012) 274–280.
[102] N. Apergis, J.E. Payne, CO2 emissions, energy usage, and output in Central America, Energy Policy 37 (2009) 3282–3286.
[103] H.-T. Pao, C.-M. Tsai, CO2 emissions, energy consumption and economic growth in BRIC countries, Energy Policy 38 (2010) 7850–7860.
[104] S.S. Wang, D.Q. Zhou, P. Zhou, Q.W. Wang, CO2 emissions, energy consumption and economic growth in China: a panel data analysis, Energy Policy 39 (2011) 4870–4875.
[105] M.E.H. Arouri, A. Ben Youssef, H. M'henni, C. Rault, Energy consumption, economic growth and CO 2 emissions in Middle East and North African countries, Energy Policy 45 (2012) 342–349.
[106] A.J. López-Menéndez, R. Pérez, B. Moreno, Environmental costs and renewable energy: Re-visiting the environmental kuznets curve, J. Environ. Manage. 145 (2014) 368–373.
[107] B. Danish, B. Zhang, Wang Wang, Role of renewable energy and non-renewable energy consumption on EKC: evidence from Pakistan, J. Clean. Prod. 156 (2017) 855–864.
[108] S.A. Sarkodie, S. Adams, Renewable energy, nuclear energy, and environmental pollution: accounting for political institutional quality in South Africa, Sci. Total Environ. 643 (2018) 1590–1601.
[109] N. Antonakakis, I. Chatziantoniou, G. Filis, Energy consumption, CO2 emissions, and economic growth: an ethical dilemma, Renew. Sustain. Energy Rev. 68 (2017) 808–824.
[110] A.C. Marques, J.A. Fuinhas, P.A. Leal, The impact of economic growth on CO2 emissions in Australia: the environmental Kuznets curve and the decoupling index, Environ. Sci. Pollut. Res. 25 (2018) 27283–27296.
[111] K. Dong, R. Sun, X. Dong, CO2 emissions, natural gas and renewables, economic growth: assessing the evidence from China, Sci. Total Environ. (2018) 640–641.
[112] H. Mahmood, The effects of natural gas and oil consumption on CO2 emissions in GCC countries: asymmetry analysis, Environ. Sci. Pollut. Res. 29 (2022) 57980–57996.
[113] M. Jaforullah, A. King, The econometric consequences of an energy consumption variable in a model of CO 2 emissions, Energy Econ 63 (2017) 84–91.
[114] G.M. Grossman, A.B. Krueger, Economic Growth and the Environment, Cambridge, Massachusetts, 1994.
[115] S. Farhani, S. Mrizak, A. Chaibi, C. Rault, The environmental Kuznets curve and sustainability: a panel data analysis, Energy Policy 71 (2014) 189–198.
[116] U.K. Pata, M. Aydin, Testing the EKC hypothesis for the top six hydropower energy-consuming countries: evidence from Fourier Bootstrap ARDL procedure, J. Clean. Prod. 264 (2020), 121699.
[117] C. Işik, M. Ahmad, U.K. Pata, S. Ongan, M. Radulescu, F.F. Adedoyin, E. Bayraktaroğlu, S. Aydın, A. Ongan, An evaluation of the tourism-induced environmental Kuznets curve (T-EKC) hypothesis: evidence from G7 countries, Sustain 12 (2020) 1–11.
[118] I. Ozturk, A. Acaravci, CO2 emissions, energy consumption and economic growth in Turkey, Renew. Sustain. Energy Rev. 14 (2010) 3220–3225.
[119] M. Shahbaz, H.H. Lean, M.S. Shabbir, Environmental kuznets curve hypothesis in Pakistan: cointegration and granger causality, Renew. Sustain. Energy Rev. 16 (2012) 2947–2953.
[120] U. Soytas, R. Sari, B.T. Ewing, Energy consumption, income, and carbon emissions in the United States, Ecol. Econ. 62 (2007) 482–489.
[121] I. Martínez-Zarzoso, A. Bengochea-Morancho, Pooled mean group estimation of an environmental Kuznets curve for CO2, Econ. Lett. 82 (2004) 121–126.
[122] H.-T. Pao, C.-M. Tsai, Modeling and forecasting the CO2 emissions, energy consumption, and economic growth in Brazil, Energy 36 (2011) 2450–2458.
[123] N. Apergis, J.E. Payne, The emissions, energy consumption, and growth nexus: evidence from the commonwealth of independent states, Energy Policy 38 (2010) 650–655.
[124] A. Robalino-López, Á. Mena-Nieto, J.E. García-Ramos, A.A. Golpe, Studying the relationship between economic growth, CO2 emissions, and the environmental Kuznets curve in Venezuela (1980-2025), Renew. Sustain. Energy Rev. 41 (2015) 602–614.
[125] G. Bölük, M. Mert, The renewable energy, growth and environmental Kuznets curve in Turkey: an ARDL approach, Renew. Sustain. Energy Rev. 52 (2015) 587–595.
[126] Y. Sugiawan, S. Managi, The environmental Kuznets curve in Indonesia: exploring the potential of renewable energy, Energy Policy 98 (2016) 187–198.
[127] M. Shahbaz, H. Mallick, M.K. Mahalik, N. Loganathan, Does globalization impede environmental quality in India? Ecol. Indic. 52 (2015) 379–393.
[128] M. Simionescu, W. Strielkowski, B. Gavurova, Could quality of governance influence pollution? Evidence from the revised environmental kuznets curve in central and eastern European countries, Energy Reports 8 (2022) 809–819.
[129] T. Luzzati, M. Orsini, Investigating the energy-environmental Kuznets curve, Energy 34 (2009) 291–300.
[130] F. Rehermann, M. Pablo-Romero, Economic growth and transport energy consumption in the Latin American and Caribbean countries, Energy Policy 122 (2018) 518–527.
[131] S. Khan, Z. Peng, Y. Li, Energy consumption, environmental degradation, economic growth and financial development in globe: dynamic simultaneous equations panel analysis, Energy Reports 5 (2019) 1089–1102.
[132] H.M. Ertugrul, M. Cetin, F. Seker, E. Dogan, The impact of trade openness on global carbon dioxide emissions: evidence from the top ten emitters among developing countries, Ecol. Indic. 67 (2016) 543–555.
[133] S. Farhani, A. Chaibi, C. Rault, CO2 emissions, output, energy consumption, and trade in Tunisia, Econ. Model. 38 (2014) 426–434.
[134] Q. Yang, J. Huo, N. Saqib, H. Mahmood, Modelling the effect of renewable energy and public-private partnership in testing EKC hypothesis: evidence from methods moment of quantile regression, Renew. Energy. 192 (2022) 485–494.
[135] K. Dong, R. Sun, H. Jiang, X. Zeng, CO2 emissions, economic growth, and the environmental Kuznets curve in China: what roles can nuclear energy and renewable energy play? J. Clean. Prod. 196 (2018) 51–63.
[136] W. Zhao, Y. Liu, L. Huang, Estimating environmental Kuznets Curve in the presence of eco-innovation and solar energy: an analysis of G-7 economies, Renew. Energy. 189 (2022) 304–314.
[137] A. Dhrifi, R. Jaziri, S. Alnahdi, Does foreign direct investment and environmental degradation matter for poverty? Evidence from developing countries, Struct. Chang. Econ. Dyn. 52 (2020) 13–21.
[138] M. Shahbaz, M. Kumar, S. Jawad, H. Shahzad, Testing the globalization-driven carbon emissions hypothesis : international evidence, Int. Econ (2019).
[139] Y. Sun, F. Yesilada, Z. Andlib, T. Ajaz, The role of eco-innovation and globalization towards carbon neutrality in the USA, J. Environ. Manage. 299 (2021), 113568.
[140] I.A. Tajudeen, A. Wossink, P. Banerjee, How significant is energy efficiency to mitigate CO2emissions? Evidence from OECD countries, Energy Econ 72 (2018) 200–221.
[141] D.I. Stern, M.S. Common, E.B. Barbier, Economic growth and environmental degradation: the environmental Kuznets curve and sustainable development, World Dev 24 (1996) 1151–1160.
[142] B.R. Copeland, M.S. Taylor, Trade, growth, and the environment, J. Econ. Lit. 42 (2004) 7–71.
[143] A. Ben Youssef, S. Hammoudeh, A. Omri, Simultaneity modeling analysis of the environmental Kuznets curve hypothesis, Energy Econ 60 (2016) 266–274.
[144] M. Wagner, The carbon Kuznets curve: a cloudy picture emitted by bad econometrics? Resour. Energy Econ. 30 (2008) 388–408.
[145] M. Wagner, The environmental kuznets curve, cointegration and nonlinearity, J. Appl. Econom. 30 (2015) 948–967.
[146] F. Bilgili, E. Koçak, Ú. Bulut, The dynamic impact of renewable energy consumption on CO2 emissions: a revisited Environmental Kuznets Curve approach, Renew. Sustain. Energy Rev. 54 (2016) 838–845.
[147] M.A. Destek, A. Sinha, Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: evidence from organisation for economic Co-operation and development countries, J. Clean. Prod. 242 (2020), 118537.
[148] U.K. Pata, A.E. Caglar, Investigating the ekc hypothesis with renewable energy consumption, human capital, globalization and trade openness for china: evidence from augmented ardl approach with a structural break, Energy (2020), 119220.
[149] M.K. Ardakani, S. Mohsen, Impact of energy consumption and economic growth on CO 2 emission using multivariate regression, Energy Strateg. Rev. 26 (2019), 100428.
[150] Y. Zhang, X. Chen, Y. Wu, C. Shuai, L. Shen, The Environmental Kuznets Curve of CO 2 Emissions in the Manufacturing and Construction Industries : A Global Empirical Analysis 79, 2019.
[151] M.A. Danish, B. Baloch, Analyzing the role of governance in CO2 emissions mitigation: the BRICS experience, Struct. Chang. Econ. Dyn. 51 (2019) 119–125.
[152] K. Du, P. Li, Z. Yan, Do green technology innovations contribute to carbon dioxide emission reduction? Empirical evidence from patent data, Technol. Forecast. Soc. Change. 146 (2019) 297–303.
[153] H. Qiao, F. Zheng, H. Jiang, K. Dong, The greenhouse effect of the agriculture-economic growth-renewable energy nexus: evidence from G20 countries, Sci. Total Environ. 671 (2019) 722–731.
[154] M. Singhania, N. Saini, Demystifying pollution haven hypothesis: role of FDI, J. Bus. Res. 123 (2021) 516–528.
[155] M. Shahbaz, S.A. Solarin, R. Sbia, S. Bibi, Does energy intensity contribute to CO2emissions? A trivariate analysis in selected African countries, Ecol. Indic. 50 (2015) 215–224.
[156] D. Lazăr, A. Minea, A.A. Purcel, Pollution and economic growth: evidence from central and eastern European countries, Energy Econ 81 (2019) 1121–1131.
[157] M.A. Destek, S.A. Sarkodie, Investigation of environmental Kuznets curve for ecological footprint: the role of energy and financial development, Sci. Total Environ. 650 (2019) 2483–2489.
[158] A.S. Mather, C.L. Needle, J. Fairbairn, Environmental kuznets curves and forest trends, Geography 84 (1999) 55–65. http://www.jstor.org/stable/40573247.
[159] P.K. Narayan, S. Narayan, Carbon dioxide emissions and economic growth: panel data evidence from developing countries, Energy Policy 38 (2010) 661–666.
[160] F.J. Hasanov, L.C. Hunt, J.I. Mikayilov, L.C. Hunt, Estimating Different Order Polynomial Logarithmic Environmental Kuznets Curves, 2021, pp. 41965–41987.
[161] D. Kaika, E. Zervas, Searching for an environmental Kuznets curve (EKC)-pattern for CO2 emissions, Recent Res Energy Env. Landsc Arch. (2011) 19–24.
[162] M. Ahmad, Y. Wu, Natural resources , technological progress , and ecological efficiency : does financial deepening matter for G-20 economies, Resour. Policy. 77 (2022), 102770.

[163] J. Huang, S. Xiang, P. Wu, X. Chen, How to control China's energy consumption through technological progress: a spatial heterogeneous investigation, Energy 238 (2022), 121965.
[164] H. Ritchie, M. Roser, Renewable Energy–Our World in Data, Our World Data. https://ourworldindata.org/renewable-energy, 2020.
[165] L. Cui, Y. Mu, Z. Shen, W. Wang, Energy transition , trade and green productivity in advanced economies, J. Clean. Prod. 361 (2022), 132288.
[166] United Nations, World Economic Situation and Prospects, 2019.
[167] C. Lee, X. Li, C. Yu, J. Zhao, The contribution of climate finance toward environmental sustainability : New global evidence, Energy Econ 111 (2022), 106072.
[168] OECD-DAC, Climate-related Development Finance Data, 2018.
[169] N.H. Stern, The Economics of Climate Change: the Stern Review, Cambridge University Press, Cambridge, 2007.