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SCIENTIFIC REVIEW

A Literature Survey of the Environmental Kuznets Curve

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ABSTRACT
Since the 1970s, the issue of environmental degradation has received considerable attention. Environmental Kuznets curve is one of the most well-known hypotheses that explains the relationship between economic growth and environmental pollution. It represents an important model that enables policymakers to deliver quality information-based decisions. In this paper, we provide the theoretical framework of the Environmental Kuznets curve and examine existing literature on the EKC hypothesis. The systematic literary survey includes studies conducted for single countries as well as for groups of countries. Most of the studies were empirically testing the existence of an inverted U-shaped relationship between economic growth and carbon dioxide emissions. Due to the different periods, sets of independent variables and methodological frameworks, the results are inconclusive, which is consistent with previous literature surveys on the same topic.

Key words: *environmental Kuznets Curve, environmental degradation, income, economic growth,* CO_2 *emissions*

JEL Classification: Q50, Q56

INTRODUCTION

Environmental degradation and lowering the quality of the environment has become a global problem attracting considerable attention. Although it is not a generally accepted point, authors such as Tietenberg & Lewis (2016) state that in the field of environmental economics the natural environment is viewed as commodity or asset with many qualitative attributes. The natural environment can be used as a source of renewable resources, but also as aesthetic consumer goods. Even today, there are ongoing discussions between economists and ecologists about a desirable or acceptable level of environmental pollution. The point that most economists and ecologists see as common is that zero pollution is neither desirable nor sustainable. Ecologists emphasise that the environment has limited waste processing power and that environmental pollution occurs only when waste is deposited in the environment outside its assimilation capacity, i.e. beyond its ability to timely decompose waste. Accordingly, the discharge and disposal of waste must not exceed the renewable assimilation capacity of the environment. Economists often try to challenge, or better say, extend this view, stating that it is completely rational that society pollutes outside the assimilation capacity of the environment to the extent that it collectively benefits from increased pollution through the added value of goods and services produced (Hussen, 2000).

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Simon Kuznets set up a model in 1955 that shows that relationship between income per capita and income inequality exhibits an inverted-U shape curve. As the per capita income increases, inequality of income also increases initially and then begins to decline after a certain turning point. In other words, the income growth in the initial stages has unequal income distribution, and then, income distribution gains greater equality with economic growth (Kuznets, 1955). This empirical phenomenon is known as the Kuznets curve. From the 1990s, this curve gets a novel interpretation. Empirical evidence that both the level of environmental degradation and income per capita follow the same inverted-U shape has been found. Therefore, the environmental Kuznets curve (EKC) now becomes a means of describing the relationship between the level of environmental quality and income per capita (Dinda, 2004).

Before creating the concept of EKC, the limited ability of the environment to absorb waste has been in the focus of scientific and professional discussions. After establishing the theoretical model of EKC, the focus shifted to the necessity of achieving and maintaining economic growth to overcome the problems of environmental pollution. High economic growth rates are the basis of all developing countries' policies, resulting in extremely high environmental costs, primarily in terms of urban and industrial waste accumulation, deterioration of air, land and water quality, loss of biodiversity, climate change and global warming (Gill, Viswanathan, & Hassan, 2017). Thus, economic growth in developing countries will produce more pollution than economic growth in developed countries due to the level of technological progress and innovation. This systematic relationship between economic development and the environment is an assumption on which the EKC hypothesis has been developed. Webber & Allen (2010) have taken the view that EKC has important implications, primarily that developing countries should direct their policies to achieve rapid economic growth, rather than adopting and implementing environmental policies. They state that "economic growth ultimately leads to the achievement of both ecological and economic goals, while pro-environmental policies only slow down economic growth" (Webber & Allen, 2010). The term "environmental Kuznets curve" was coined by Panayotou (1993).

The first studies that empirically tested and demonstrated the existence of the inversed-U shape of the EKC between income and environmental pollution were carried out by Grossman & Krueger (1991) and Shafik & Bandyopadhyay (1992). Studying the interdependence between air quality and economic development, Grossman & Krueger (1991) found the inversed-U shape curve between SO_2 and smoke and income per capita. This is the first formal confirmation of the EKC validity. These results indicated that the concentration of air pollutants increase with the income level at first, and then decrease at higher levels of income. The EKC was further popularised in the 1992 World Bank Development Report, which states that as revenues increase, the demand for improving the quality of the environment will increase along with the resources available for investment (IBRD, 1992). This position is also supported by Beckerman (1992), who states that although economic growth usually leads to environmental degradation in the early stages, it ultimately represents the best and possibly the only way to achieve an adequate quality of the environment in most countries.

Thus far, a vast number of papers have been published which empirically investigate and analyse the issues of interdependence between environmental quality and economic growth, using diversified tools of econometric analysis. It is important to point out that the hypothesis of environmental Kuznets curve was, and still is today, particularly interesting in this type of research. According to Mitić, Munitlak Ivanović, & Zdravković (2017), empirical models that analyse the environmental Kuznets curve most often observe the indicator of environmental degradation as a dependent variable in relation to the indicators of economic development and their squares as the independent variable.

The remainder of this paper is organised as follows. In the next section, the theoretical framework of the EKC is presented. Special emphases are given to the factors of influence on the shape of the EKC curve, and econometric specification of the model. Rest of the paper provides an overview of EKC research for both individual and groups of countries. Last part of the paper gives several concluding remarks.

THEORETICAL FRAMEWORK OF THE ENVIRONMENTAL KUZNETS CURVE

The intuition behind the EKC is intuitively attractive (Dinda, 2004). "Environmental Kuznets curve represents a hypothetical link between different indicators of environmental degradation and income per capita" Stern (2004). This curve postulates that in the early stages of economic development, industrialisation and urbanisation greatly exhaust natural resources and create industrial and urban waste. At this stage, economic growth and pollution are interconnected, in the sense that economic growth also increases environmental pollution (Gill, Viswanathan & Hassan, 2018). Dasgupta et al. (2002) confirm this view, stating that pollution is rising rapidly in the early stages of industrialisation, as the main goal is to increase material production, and people are more interested in business and earning revenues rather than having clean air and water. Rapid achievement of economic growth implies increased use of natural resources and emissions of pollution, which creates greater pressure on the quality of the environment. People at these stages of economic growth are too poor to invest in improving the quality of the environment and most often neglect the consequences that growth makes to the environment. It is said that multi-dimensional poverty is often high in the initial stages of economic development, and environmental conservation is often ignored (Asumadu-Sarkodie & Strezov, 2019a). Therefore, at this stage, there is a positive linear link between economic growth and environmental pollution. Reduction of pollution comes with the advancement of the process of industrialisation, technical and technological improvements and growth of the service sector (Panayotou, 1993). In other words, pressure on the environment is growing faster than income in the early stages of development and slows down with GDP growth at higher levels of income. "Green economy and especially renewable energy are crucial for reducing poverty, a particularly significant problem for developing countries" (Todorović, 2018).

Only in the later phases of economic development, there is a significant increase in income levels which, in combination with an increase in institutional quality, awareness of environmental sustainability and high diffusion of technology and innovation, causes a decrease in environmental degradation (Asumadu-Sarkodie & Strezov, 2019a). Therefore, it is evident that EKC represents a well-established relationship between the level of economic activity and the pressure on the environment. "In brief, Environmental Kuznets Curves are statistical artefacts that summarise a few important aspects of collective human behaviour in two-dimensional space." Dinda (2004). As it is stated above, at higher levels of income, people start to value the environment more. Therefore, there are more requirements for environmental quality in the advanced stages of economic development. At higher levels of economic development, structural changes towards information-intensive industries and services, together with increased environmental awareness, implementation of environmental protection regulations, better technology and higher environmental costs, result in a gradual reduction in environmental degradation. When income per capita crosses the turning point of EKC, it is assumed that improving the quality of the environment begins to grow. Therefore, this could be an overview of the natural process of economic development from an agrarian and industrial economy to a clean economy based on information-intensive activities and services sector (Arrow et al., 1995). All this speaks in favour of the fact that the environmental indicator is a reversed function of income per capita. Precisely this systematic relationship between income per capita and environmental quality is the core of EKC hypothesis. Pollution increases with an increase in revenues in the early stages of economic development and is reduced with an increase in revenue in the later stages of economic development, as shown in Figure 1.

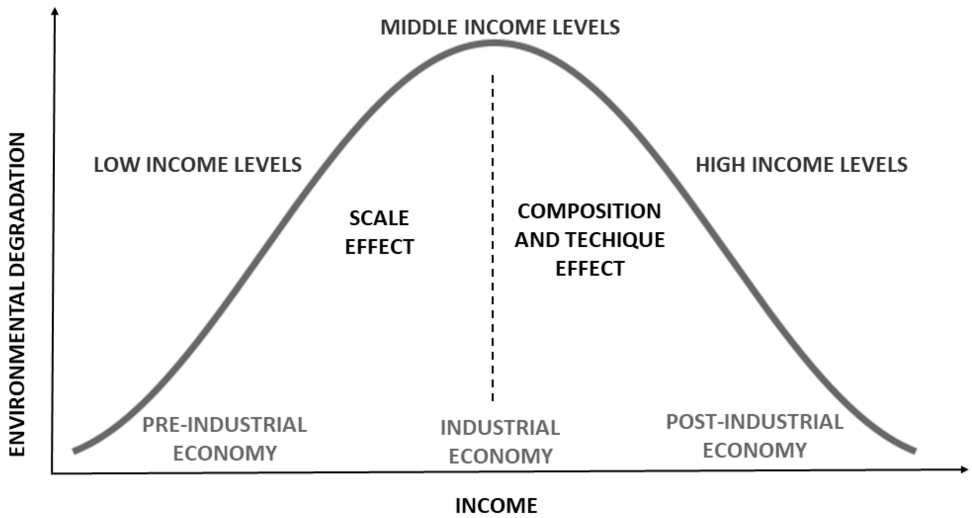

Figure 1. Environmental Kuznets Curve

Source: Authors

The conceptual framework of EKC may imply that environmental problems that arise as a result of economic growth are automatically solved in later stages of economic development. In a dynamic economic environment, with technological advances and increase in population preferences toward a better environment, economic growth does not pose a threat to environmental quality, but rather a condition for raising its' quality. Under the assumption of the truthfulness of the EKC hypothesis, economic growth should not be viewed as a threat to the quality of the environment, but as a means for eventual improvement of the environment. This idea also underwent an administrative embodiment in the new idea of sustainable economic development in *Our Common Future* Report published by the World Commission on Environment and Development in 1987 (Stern, 2004). Lapshina, Bakaeva & Sotnikova (2017) claimed that a transition to the sustainable development concept is a necessity, especially for the urban territories.

EKC had a significant impact on the economic policies of both developing and developed countries alike. Even the priorities of the International Monetary Fund and the World Bank have been focused on supporting policies for growth. Therefore, economic growth has become the primary goal of developing countries without proper consideration of environmental issues. According to van den Bosch & Telenius (2016), changes in the environment are evident all over the world and take place at a faster pace than previously thought. For this reason, it is imperative that governments now take steps to reverse and adapt to the damage already done. The empirical results of the EKC indicate that economic growth can support environmental improvements if appropriate policies are taken. However, the consensus is that effective environmental policy can only be achieved in terms of income growth. However, before adopting a policy, it is important to understand the nature and the causal link between economic growth and the quality of the environment (Coondoo & Dinda, 2002). Therefore, Dinda (2004) puts a relevant question here: Can economic growth be part of the solution and not the cause of environmental problems? This was the basic motivation for empirical studies in the search for proofs of interdependence between income growth and environmental degradation.

Factors affecting the inversed-U shape of the environmental Kuznets Curve

Factors that influence the inverted-U shape between environmental degradation and income levels are (Asumadu-Sarkodie and Strezov, 2019a):

- income elasticity of environmental quality
- scale, composition and technique effect
- international trade

"Income elasticity of environmental quality demand is the proportional change in environmental quality demand per the proportional change in income level." (Asumadu-Sarkodie & Strezov, 2019a). They further state that demand for quantity instead of quality means an increase in exploitation of natural resources and manipulation of environmental regulations and industry standards to attract polluting industries from developed countries. Only when the level of income and the living standard increase, people are ready to pay for a better environment. In other words, the most common explanation for the EKC form is the idea that people attach greater value to ecological aspects only when the country achieves a sufficiently high standard of living (Edenhofer et al., 2011, Girod et al., 2014).

The interdependence between environmental degradation and economic development takes place through three effects: the effects of scale, composition and technique (Grossman & Krueger, 1991). These effects are presented in Figure 1.

Economic development has a negative impact on the environment, while the scale effect is in place. Higher production volumes require greater exploitation of natural resources, thus increasing environmental degradation. Furthermore, economic development implies a high consumption of non-renewable energy sources that is cheaper than renewable energy (Asumadu-Sarkodie & Strezov, 2019a). The use of non-renewable energy for industrial processes can reduce production costs and provide a greater volume of manufactured goods and services, but it nevertheless encourages the increase of harmful emissions, primarily from industrial processes (Owusu & Asumadu, 2016). Furthermore, the composition effect implies that economic development has a negative or positive impact on the environment, depending on structural changes in the economy (Asumadu-Sarkodie & Strezov, 2019b). As the level of income grows, the structure of the economy is changing and economic activities that produce less pollution gradually increase. Environmental degradation is increasing as the structure of the economy is directed from agricultural to industrial activities, but also with a structural change from the energy-intensive industry to services and knowledge-based innovations and technologies. The technique effect implies that economic development has a positive impact on the environment. As countries with higher levels of income invest more in research and development (Komen et al., 1997), this allows the replacement of old technologies that emit large quantities of pollution with new, cleaner and more sophisticated technologies. This combined with strict environmental regulations and industry standards, leads to an improvement in the quality of the environment. Taking all three effects into account, EKC suggests that the negative impact of the scale effect on the environment tends to govern at the initial stages of growth. It will ultimately be overcome by the positive impact of the composition and technique effect that tends to reduce the level of harmful emissions (Dinda, 2004; Asumadu-Sarkodie & Strezov, 2018).

Certain economists, such as Lee & Roland-Holst (1997) and Jones & Manuelli (1995) argue that trade is not the main cause of environmental degradation. However, free trade has diversified and contradictory effects on the quality of the environment, as it also increases pollution and motivates their reduction (Dinda, 2004). Through the scale effect, the quality of the environment decreases because increasing the volume of trade, and above all exports, increases the size of economic activities, which increases pollution. On the other hand, trade improves the environment through composition and technique effects. Openness and trade liberalisation leads to the specialisation of countries in those sectors where they have a competitive advantage. However, if a competitive advantage arises from liberal environmental regulations, then trade openness will degrade the environment. Trade liberalisation, through the composition effect, is also called the pollution haven hypothesis. If the environmental protection regulations are weak, they attract energy-intensive industries that emit large quantities of pollution. It is most often the case that developed countries transfer their industrial capacities to developing countries with poor environmental legislation. Poor environmental policies and regulations in developing countries are becoming a source of comparative advantage, and therefore, changes in the trade structure promote environmental degradation in these countries (Sun, Zhang & Xu, 2017). In the same way, if innovation, research and development, as well as clean and modern technologies are transmitted through foreign direct investments from developed countries to developing countries, this can reduce the level of pollution.

An econometric framework of the environmental Kuznets curve

The studies that investigated the EKC hypothesis have common characteristics of the used data and methodologies. In other words, regardless of the different methods and techniques used in the analysis of the EKC, almost all follow a similar model specification. Most of the data used in this type of research are panel data. Therefore, the basic specification of the EKC model is as follows:

$$y_{i,t} = \alpha_{i,t} + \beta_1 x_{i,t} + \beta_2 x_{i,t}^2 + \beta_3 x_{i,t}^3 + \beta_4 z_{i,t} + \varepsilon_{i,t},$$

where y represents environmental indicators, α is the constant, x, x^2 and x^3 represent the income level, the squared income level and the cubical income level, β_k are the coefficients estimates of the regression, z represents other indicators of interest for the model, i is a spatial index (country), t is the time index (year), and ε is white noise.

Based on the econometric specification of the model, the testing of the relationship between environmental pollution and income levels can provide several interpretations (Asumadu-Sarkodie & Strezov, 2019a; Dinda, 2004). We have divided these interpretations into three groups. The first group displays linear relationships, which are presented in Figure 2.

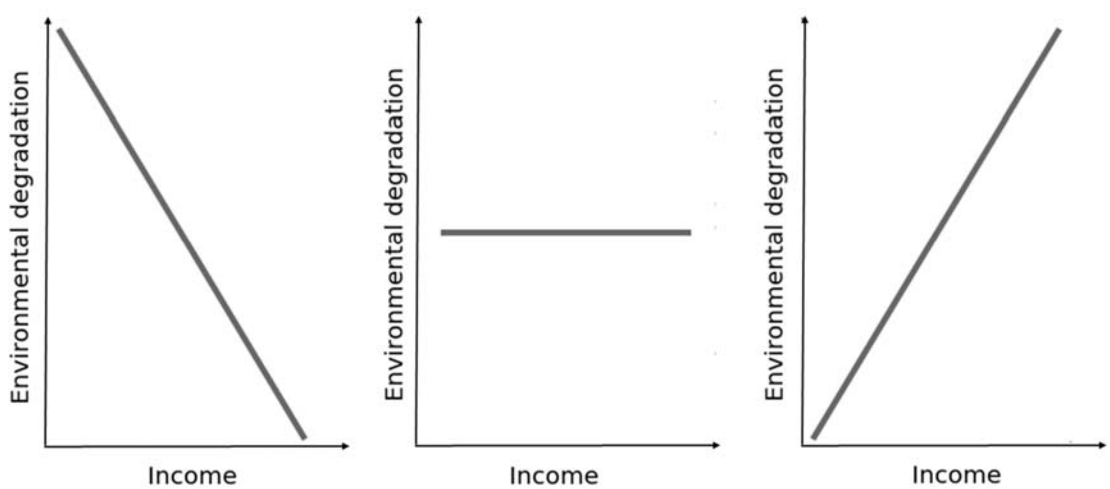

Figure 2. A linear relationship between environmental pollution and income

Source: Authors

The left-hand plot of the Figure 2 represents a case where a monotonically decreasing relationship between environmental degradation and income exists ($\beta_1 < 0$ and $\beta_2 = \beta_3 = 0$). Middle plot of the Figure 2 represents a situation where no relationship between environmental degradation and income is detected ($\beta_1 = \beta_2 = \beta_3 = 0$), while the right-hand plot of the Figure 2 illustrates a case where a monotonically increasing relationship between environmental degradation and income is present ($\beta_1 > 0$ and $\beta_2 = \beta_3 = 0$).

The second group represents the U shaped relationships between environmental degradation and income levels. These relationships are graphically presented in Figure 3.

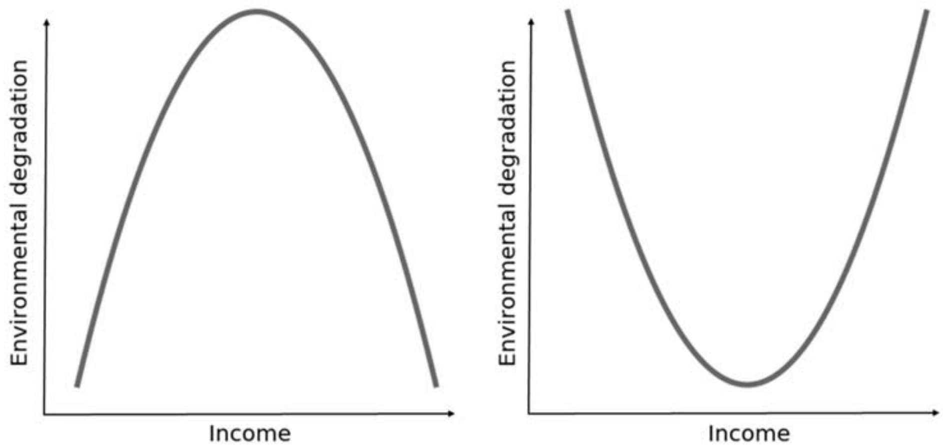

Figure 3. Inverted-U and U shaped relationship between environmental pollution and income

Source: Authors

Left-hand side of the Figure 3 shows a situation where an inverted-U shaped relationship exists, i.e. which supports the EKC hypothesis ($\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 = 0$). On the other hand, right-hand side of Figure 3 represents a situation where the relationship has the shape of U shaped curve ($\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 = 0$).

Third and final group represents the N shaped relationships between environmental degradation and income levels, which relationships are graphically shown in Figure 4.

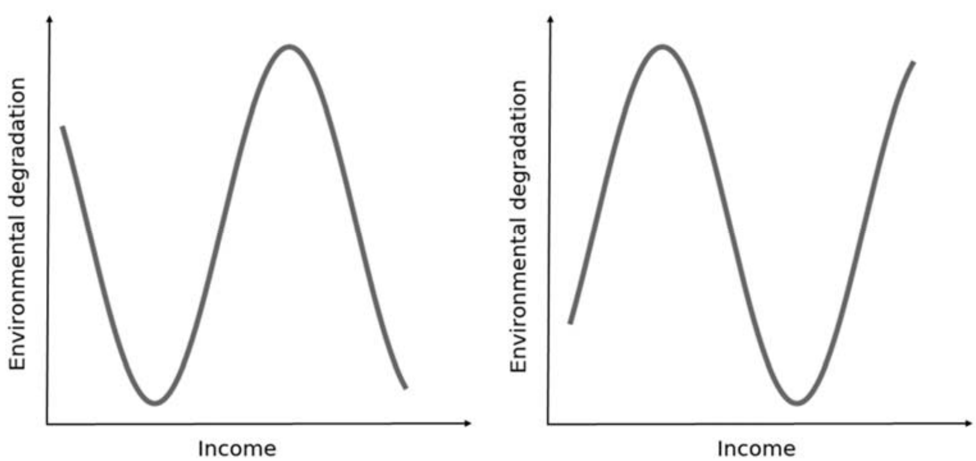

Figure 4. Inverted-N and N shaped relationship between environmental pollution and income

Source: Authors

Left-hand side of the Figure 4 visualises an inverted-N shaped relationship ($\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 < 0$). Right-hand side of the Figure 4 represents a situation where there is a N shaped curve ($\beta_1 > 0$, $\beta_2 < 0$ и $\beta_3 > 0$).

Based on all the above mentioned, the EKC hypothesis is valid only in the case when $\beta_1 > 0$, $\beta_2 < 0$ и $\beta_3 = 0$, i.e. left-hand side of the Figure 3. The turning point of the curve is then obtained as a maximum of the quadratic function:

$$x^* = -\frac{\beta_1}{2\beta_2}.$$

A vast number of econometric studies have used the previous model to test the existence of an EKC for a wide range of environmental indicators. It is necessary to point out that the values of the indicators in this type of research are often used in their logarithmic form.

SELECTED LITERATURE REVIEW FOR SINGLE COUNTRIES

As mentioned above, there is an extensive number of studies which tested the environmental Kuznets curve hypothesis for individual countries. Some countries, such as China, Turkey, Malaysia and Pakistan, etc. have been of great interest in the context of testing EKC hypothesis, but there is a certain number of countries that have not yet been examined in this context.

For example, Ahmad et al. (2017) examined the validity of EKC in Croatia using Autoregressive Distributed Lag (ARDL) Model and Vector Error Correction Model (VECM) on quarterly data for the period 1992Q1-2011Q1. Their results confirmed the validity of the EKC, i.e. there is an inverted U-shape relation between CO_2 emissions and economic growth in the long run.

Similarly, Kang et al. (2016), Lacheheb et al. (2015), and Saboori et al. (2012) tested the relationship between economic growth and CO_2 emissions in China (1997–2012), Algeria (1971-2009), and Malaysia (1980-2009), respectively. Using a spatial panel data model, Kang et al. (2016) showed the existence of inverted-N EKC in China. Oppositely, Lacheheb et al. (2015) used ARDL co-integration framework and showed that EKC hypothesis does not exist in Algeria, while results from Saboori et al. (2012) indicated that there is support for the EKC hypothesis in Malaysia, again using ARDL methodology. Another study that examined the validity of EKC hypothesis for the period 1960-2007 in China was conducted by Šimurina & Dobrović (2011). The authors used regression analysis and the following variables: economic growth (per capita GDP) and carbon dioxide (CO_2) emissions per capita. Results presented by Kang et al. (2016), indicate that the EKC hypothesis is rejected for China, but here a linear relationship fits the data more properly. Another study that does not support the EKC hypothesis was conducted by Al-Mulali et al. (2015). They were examining Vietnam for the period 1981-2011 and showed that the relationship between GDP and pollution is positive in both the short and long run, follow an inverted-U shape. To the contrary, Li et al. (2016) found that EKC hypothesis is supported in China. The selected methodology was a dynamic panel model with Generalized Method of Moments (GMM) estimator and ARDL model with alternative panel estimator, to test EKC hypothesis in the period 1996-2012.

On the other hand, in the case of Spain, Esteve & Tamarit (2012) examine the long-run relationship between per capita carbon dioxide and per capita income over the period 1857–2007. They utilised threshold cointegration techniques, and their results suggest the existence of an inverted-U shape between two selected variables, supporting EKC hypothesis.

Saboori & Sulaiman (2013) employed ARDL methodology, Johansen–Juselius maximum likelihood approach, and VECM to test the relationship between economic growth, carbon dioxide emissions and energy consumptions. These authors test the EKC hypothesis in Malaysia for the period 1980-2009, by employing both the aggregated and disaggregated energy consumption data. Their results did not support the EKC hypothesis when aggregated energy consumption data was used. However, when data were disaggregated based on different energy sources, their study does show evidence of the EKC hypothesis.

For Romania, Shahbaz et al. (2013) used ARDL cointegration tests to analyse the dynamic relationship between economic growth, energy consumption and carbon dioxide emissions for the period 1980-2010. Their empirical results suggest that the EKC is found both in long-and-short runs. Same results were obtained in the case of Pakistan for the period 1971-2008. Here Ahmed & Long (2012) tested the existence of EKC using data for carbon dioxide emissions, economic growth, energy consumption, trade liberalisation and population density. These authors utilised the cointegration analysis using the ARDL bounds testing the approach on yearly data. The same methodology – ARDL has been used by Al-Mulali et al. (2015) for Vietnam, Bölük & Mert (2015) for Turkey, Jalil (2012) for China, and Mrabet & Alsamara (2017) for Qatar.

Bölük & Mert (2015) test the validity of the EKC hypothesis during 1961-2010. Their results show the existence of a U-shaped relationship between per capita greenhouse gas emissions and income in Turkey. Jalil (2012) test the long-run relationship between openness and income inequality in the period 1952-2009. It was found that income inequality rises with the increase of openness and then starts to fall after a critical point, which is in line with the EKC hypothesis. Mrabet & Alsamara (2017) tested the EKC hypothesis using two different environment indicators: the carbon dioxide emissions and the ecological footprint in the period 1980–2011. The variables used in this study are the real gross domestic product, energy use, financial development, trade openness, carbon dioxide emissions and the ecological footprint. Their results suggest that the EKC hypothesis is not valid in Qatar when they use carbon dioxide emissions, whereas the EKC hypothesis is valid when using the ecological footprint.

Furthermore, Al-Mulali et al. (2016) investigated the EKC hypothesis for Kenya from 1980 to 2012 using the ARDL approach again. Their results showed that fossil fuel energy consumption, GDP, urbanisation, and trade openness increased air pollution mutually in the long run and short run. Al-Mulali et al. (2016) showed that the EKC hypothesis does exist in Kenya. Zambrano-Monserrate et al. (2018) and Tiwari et al. (2013) used ARDL and VECM methodology to test the EKC hypothesis for Peru (1980-2011) and India (1966-2011), respectively. Zambrano-Monserrate et al. (2018) showed that EKC hypothesis does not exist in Peru, while Tiwari et al. (2013) results suggested the presence of EKC in the long run as well as in short run in India.

For Malaysia, Ali et al. (2017) investigated EKC using the following variables: the impact of real GDP per capita, financial development, trade openness, foreign direct investments, and energy consumption on CO_2 emissions throughout 1971-2012. The authors employed ARDL bound test and the Granger causality test to investigate the long-run relationship between the selected variables. Their results suggest that the EKC hypothesis exists in Malaysia. Using the same methodology, Jalil & Mahmud (2009) tested the EKC relationship between carbon dioxide emissions and per capita real GDP in the period 1975-2005 in the case of China. These authors used the following variables: carbon emissions, energy consumption, income, and foreign trade. Jalil & Mahmud (2009) found a quadratic relationship between income and carbon dioxide emissions, supporting the EKC relationship.

Fodha & Zaghdoud (2010) used cointegration analysis to show that the EKC hypothesis was valid in Tunisia for the period 1961-2004. Similarly, Lau et al. (2014) employing the bounds testing approach and Granger causality methodology and got results that the EKC hypothesis does exist for Malaysia in the period 1970-2008. For Saudi Arabia, Mahmood & Alkhateeb (2017) employed ARDL cointegration tests in order to test the impacts of trade and income level on carbon dioxide emissions in the period 1970-2016. The authors' results showed inveterate the EKC hypothesis. For Cambodia, Ozturk & Al-Mulali (2015) used the Generalized Method of Moments and the Two-stage Least Squares to investigate whether better governess and corruption control help to form the inverted U-shaped relationship between income and pollution for the period of 1996–2012. Their results suggest that the EKC hypothesis was not confirmed in Cambodia. Nasir & Rehman (2011) and Shahbaz et al. (2012) investigated the EKC hypothesis in case of Pakistan for the period 1972–2008, and 1971–2009, respectively. Both Nasir & Rehman (2011) and Shahbaz et al. (2012) confirmed the existence of the EKC for Pakistan.

Table 1. Summary of studies on individual countries

Author	**Period**	**Country**	**Methodology**	**Variables**	**EKC**
Ahmad et al. (2017)	1992Q1-2011Q1	Croatia	ARDL & VECM Granger Causality	CO_2, GDP	Yes
Ahmed & Long (2012)	1971-2008	Pakistan	ARDL	CO_2, GDP EC, TO, PD	Yes
Ali et al. (2017)	1971-2012	Malaysia	ARDL & VECM Granger Causality	CO_2, GDPpc, FD, TO, FDI, EC	Yes
Al-Mulali, Saboori & Ozturk (2015)	1981-2011	Vietnam	ARDL	CO_2, GDPpc, EL (fossil fuels) EL (renewables), CA, LF, EX, IM	No
Al-Mulali, Solarin, & Ozturk (2016)	1980-2012	Kenya	ARDL & VECM Granger Causality	CO_2, GDPpc, EL (fossil fuels) EL (renewables), FD, TO, UR	Yes
Bölük & Mert (2015)	1961-2010	Turkey	ARDL	CO_2, GDPpc, EL (renewables)	Yes
Esteve & Tamarit (2012)	1857-2007	Spain	threshold cointegration techniques	CO_2, GDPpc	Yes
Fodha & Zaghdoud (2010)	1961-2004	Tunisia	panel cointegration and VECM Granger Causality	CO_2, GDPpc, SO_2	Yes
Jalil & Mahmud (2009)	1975-2005	China	ARDL	CO_2, GDPpc, EC, TO	Yes
Jalil (2012)	1952-2009	China	ARDL	OPEN, Gini, FD, INF,	Yes
Kang, Zhao & Yang (2016)	1997-2012	China	the spatial panel data model	CO_2, GDPpc, TO, CC, UR, PD	Yes
Lacheheb Rahim & Sirag (2015)	1971-2009	Algeria	ARDL	CO_2, GDPpc, CF, TO	No
Lau, Choong & Eng (2014)	1970-2008	Malaysia	bounds testing & VECM Granger Causality	CO_2, GDPpc, FDI, TO	Yes
Li et al. (2016)	1996-2012	China	dynamic panel model, GMM, ARDL	CO_2, IWW, IWS, GDPpc, EC, TO, UR	Yes
Mahmood & Alkhateeb (2017)	1970-2016	Saudi Arabia	ARDL	CO_2, GDP, TR	Yes
Mrabet & Alsamara (2017)	1980-2011	Qatar	ARDL	CO_2, EF, GDPpc, EC, FD, TO	No (for CO_2) Yes (for EF)
Nasir & Rehman (2011)	1972-2008	Pakistan	panel cointegration and VECM Granger Causality	CO_2, GDPpc, EC, TO	Yes
Ozturk & Al-Mulali (2015)	1996-2012	Cambodia	GMM & TSLS	CO_2, GDP, EL, TO, COR, GOV	No

Author	Period	Country	Methodology	Variables	EKC
Saboori & Sulaiman (2013)	1980-2009	Malaysia	ARDL, Johansen–Juselius maximum likelihood approach, VECM Granger Causality	CO_2, GDPpc, EC	No (when aggregated EC) Yes (when disaggregated EC)
Saboori, Sulaiman & Mohd (2012)	1980-2009	Malaysia	ARDL & VECM Granger Causality	CO_2, GDPpc	Yes
Shahbaz et al. (2012)	1971-2009	Pakistan	ARDL & VECM Granger Causality	CO_2, GDPpc, EC, TO	Yes
Shahbaz et al. (2013)	1980-2010	Romania	ARDL	CO_2, GDPpc, EC	Yes
Šimurina & Dobrović (2011)	1960-2007	China	Regression analysis	CO_2, GDPpc	No
Tiwari, Shahbaz & Hye (2013)	1966-2011	India	ARDL & VECM Granger Causality	CO_2, CC, GDPpc, TO	Yes
Zambrano-Monserrate et al. (2018)	1980-2011	Peru	ARDL & VECM Granger Causality	CO_2, GDPpc, EL, DNG, PC	No

Source: Authors

Note: **Variables**: CO_2 – carbon dioxide emissions, GDP – gross domestic product, GDPpc - gross domestic product per capita, TO – trade openness, CC – coal consumption, UR – urbanisation, PD – population density, CF – gross fixed capital formation, EC – energy consumption, EL – electricity consumption, CA – capital, LF – labour force, EX – exports, IM – imports, OPEN - openness (further divided in trade ratio, average tariff rates, effective tariff rates, economic globalization and overall globalization), FD – financial development, INF – inflation, EF - ecological footprint, FDI – foreign direct investments, DNG – dry natural gas, PC – petroleum consumption, SO_2 – sulfur dioxide emissions, TR – total trade, COR – corruption index, GOV – government effectiveness index, IWW – industrial waste water, IWS – industrial waste solid emissions, **Methodology**: GMM – Generalized Method of Moments, TSLS – Two-stage Least Squares, ARDL – Autoregressive Distributed-lagged model, VECM – Vector error correction model.

SELECTED LITERATURE REVIEW FOR GROUPS OF COUNTRIES

The EKC analysis can be performed and extended by considering a region or a group of countries instead of a single country. There are many available studies exploring relationships described above within various regions and groups of countries.

MENA countries are particularly interesting for researchers. According to the analysis performed on single MENA counties, the results are very heterogeneous. Arouri et. al (2012) investigated the nature of the causality relationship between carbon dioxide emissions, energy consumption, and real GDP for 12 MENA countries (Algeria, Bahrain, Egypt, Jordan, Kuwait, Lebanon, Morocco, Oman, Qatar, Saudi Arabia, Tunisia, and UAE) covering the time period 1981-2005. The authors utilised bootstrap panel unit root tests and cointegration techniques and estimated panel error correction models (ECM) to examine the interactions between short- and long-run dynamics of environmental variables. EKC hypothesis is tested for the MENA region for CO_2 and each country separately. At the region level findings support an inverted U-shape pattern associated with the EKC hypothesis for the MENA region.

On the other hand, at the country-level, there is poor evidence in support of the EKC hypothesis for the studied countries except for Jordan. This result is confirmed by Farhani et al. (2018). The authors analysed the following 10 MENA countries over the period 1990–2010: Algeria, Bahrain, Egypt, Iran, Jordan, Morocco, Oman, Saudi Arabia, Syria, and Tunisia. The authors tested the EKC hypothesis but also considered modified EKC to explore the relationship between sustainability and human development. In addition to the variables chosen by Arouri et al. (2012), these authors added trade openness, manufacture value-added and modified HDI in the list of independent variables. Data were analysed using panel data methods: panel long-run estimates (FMOLS and DOLS) and panel VECM. Panel data results offer support in favour of the EKC hypothesis, i.e., there is an inverted U-shape relationship between environmental degradation and income. Unlike two studies which applied parametric approaches on the panel of data sets from the MENA region and whose findings supported the EKC hypothesis, research by Fakih and Marrouch (2019) led to opposite findings. These authors examined the EKC hypothesis for the selected ten countries in the MENA region and covered the period from 1980 to 2010. The analytical framework included only two variables: carbon dioxide emissions and real GDP. The approach applied in this study was a non-parametric regression model and technique in estimating the functional form of the curve is the deviance difference test. Findings revealed that the EKC hypothesis is rejected, i.e., provide evidence against the postulated inverted-U shaped relationship between pollution and the level of economic development.

Another interesting group of countries is the Organisation for Economic Co-operation and Development (OECD). Churchill et al. (2018) examined the EKC hypothesis for 20 OECD countries for the period between 1870 and 2014. In order to achieve this goal, the authors investigated cross-sectional correlations. The specification of the model was the following. The dependent variable was carbon dioxide emissions, while the set of independent variables consisted of GDP, the square of GDP, the ratio of trade population, population, financial development. Utilising recently developed panel data estimators that account for cross-sectional dependence and parameter heterogeneity, the EKC hypothesis is verified for the panel with three of the four estimators (MG, AMG, and PMG). The similar results were obtained by Lau et al. (2018) who studied the EKC hypothesis in 18 OECD countries for the period 1995-2015. However, the main aim of the study was to investigate the effects of electricity production from a nuclear source, electricity production from non-renewables and trade openness on CO_2 emissions. These authors employed technique Generalized Methods of Moments (GMM) and panel Fully Modified Ordinary Least Squares (FMOLS). The results support the EKC hypothesis in OECD countries where nuclear energy plays a pivotal role in protecting the environment.

Another group of countries has been very popular among researcher, and that is the Association of Southeast Asian Nations (ASEAN). Budhi Utomo & Widodo (2019) tested the EKC hypothesis in 9 ASEAN countries within the period from 2007 to 2014. Utilising advanced econometric technique Generalized Methods of Moments (GMM) estimator they determined how economic growth and energy use influence CO_2 emissions. One of the significant findings is that EKC is based on economic growth for ASEAN countries, but that energy use has a positive and not significant effect. Heidari et al. (2015) performed EKC analysis for 5 ASEAN countries in the period from 1980 to 2008 using the panel smooth transition regression model. This flexible model has two regimes: levels of GDP per capita below 4686 USD (1st regime) and GDP per capita above 4686 USD (2nd regime). In the 1st regime, there is an increase in environmental degradation with economic growth while the 2nd regime showed a reversed trend. The authors have derived results which support the validity of the EKC hypothesis in these ASEAN countries. However, Zhu et al. (2016) state that there is only poor evidence for supporting the EKC hypothesis. These authors used panel quantile regression model to investigate the influence of foreign direct investment, economic growth and energy consumption on carbon emissions in five ASEAN countries. The chosen period is from 1981 to 2011.

EKC hypothesis was also tested in BRIC countries. Pao & Tsai (2010) investigated the impact of economic growth and energy consumption on in BRIC countries from 1971 to 2005. The methodology included panel cointegration techniques and Granger causality. The overall results support the EKC hypothesis.

Lau at al. (2018) continued examining the EKC phenomenon. They focused on 100 developed and developing nations by considering the role of institutional quality. The countries were classified into three groups: low income (13 countries), lower-middle income (28 countries), upper-middle income (25 countries) and high income (34 countries) and the analysis was conducted for each group as well as for all countries together. The selected period was from 2002 to 2014. Independent variable was CO_2 emissions, while GDP, the square of GDP, ratio of trade population, institutional quality, FDI, trade openness ratio were chosen as independent variables. The methodological framework included the generalised method of moments estimators. Independent variable was CO_2 emissions, while GDP, the square of GDP, ratio of trade population, institutional quality, FDI, trade openness ratio were chosen as independent variables. The results provide evidence in support of the EKC hypothesis and an inverted U-shaped relationship between economic growth and CO_2 emissions for the whole group of 100 countries.

On the other hand, the analysis conducted on the income-based groups shows a strong influence of economic development stage on the existence of inverted U-shaped EKC. It is shown that the EKC hypothesis is verified only developed, i.e., in high-income countries, but not in developing nations. Testing the EKC hypothesis in countries classified by income was also performed by Shahbaz et al. (2019). They tested the EKC hypothesis for 86 high-income, middle-income, and low-income countries over the period 1970–2015. For this goal, the cross-correlation was applied to understand the relationship between globalisation and energy consumption in terms of time lags and leads. Their findings revealed that there is clear evidence in support of the EKC hypothesis in 64 out of the 86 countries. Zhang & Meng (2019) investigated the EKC hypothesis using data from 1996 to 2014 on CO_2 emissions from 115 countries with multiple levels of per capita GDP and internet penetration. The chosen countries were grouped by income into low-income, lower-middle income, upper-middle-income and high-income countries. They estimated functional forms with quadratic transformations of regressors. Empirical results verify the existence of the EKC and reveal that internet penetration does generally reduce the actual income level beyond which pollution begins to decrease.

Developed countries were in the focus of Beșe & Kalayci (2019). They tested the EKC hypothesis for Denmark, the United Kingdom, and Spain for the period 1870-2014. The authors have examined long-term relationships between GDP, CO_2, energy consumption, and the square of GDP using Johansen cointegration test. According to the results, the EKC hypothesis is rejected.

USA countries were analysed by Işık et al. (2019). The authors tested the EKC hypothesis for ten selected USA states in the period from 1980 to 2015. These chosen states have the highest levels of carbon dioxide emissions in the USA. The influence of the following independent variables on the CO_2 emissions was estimated: real GDP, population, renewable and fossil energy consumptions. The panel estimation method was applied with cross-sectional dependence. The empirical results verify the EKC hypothesis and indicate inverted U-shaped for only five out of ten states.

Table 2. Summary of studies on groups of countries

Author	Period	Country	Methodology	Variables	EKC
Arouri et al. (2012)	1981-2005	12 MENA countries	Bootstrap panel cointegration techniques, and ECM	CO_2, EC, GDPpc	Yes
Beșe & Kalayci (2019)	1960-2014	Denmark, United Kingdom, & Spain	ARDL, Toda and Yamamoto Granger non-causality test, VAR Granger Causality	CO_2, EC, GDPpc	No
Budhi Utomo & Widodo (2019)	2007-2014	9 ASEAN countries	GMM	CO_2, EC, GDPpc	Yes
Churchill et al. (2018)	1870-2014	20 OECD nations	Cross-sectional dependence, panel cointegration, MG, AMG,	CO_2, GDPpc, TR, POP, FD	Yes (3 of 4 estimators)

			PMG, CCEMG estimators		
Fakih & Marrouch (2019)	1980-2010	10 MENA countries	Non-parametric regression	CO_2, GDPpc	No
Farhani et al. (2018)	2002-2014	10 MENA countries	DOLS, FMOLS & VECM Granger Causality	CO_2, GDPpc, TO, MAV, HD, RL	Yes
Heidari et al. (2015)	1980-2008	5 ASEAN countries	Panel smooth transition regression model	CO_2, EC, GDPpc	Yes
Işık et al. (2019)	1980-2015	Ten states in USA	Panel estimation method with cross-sectional dependence	CO_2, GDP, GDPpc, EC (fossil fuels), EC (renewables), POP	Yes for five states
Lau et al. (2018)	1870-2014	100 developed and developing nations	GMM	CO_2, GDPpc, TO, INQ, FDI	Yes
Lau et al. (2018)	1995-2015	18 OECD countries	GMM & FMOLS	CO_2, GDPpc, TO, EL (nuclear), EL (non-renewable)	Yes
Pao & Tsai (2010)	1971-2005	BRIC	Panel cointegration, VECM Granger causality	CO_2, EC, GDPpc	Yes
Shahbaz et al. (2019)	1970-2015	86 countries	Cross-correlation	GLO, EC	Yes for 64 countries
Zhang & Meng (2019)	1996–2014	115 countries	Functional forms with quadratic transformations of regressors	CO_2, GDPpc, INI, INT, EL, TR, FDI, INF, URB, IND, AR, PD, POPGR, PRW, DEM	Yes
Zhu et al. (2016)	1981-2011	5 ASEAN countries	Panel quantile regression model	CO_2, EC, GDPpc, POP, FDI, TO, INDS, FD	No

Source: Authors

Note: **Variables**: CO_2 – carbon dioxide emissions, GDP – gross domestic product, GDPpc - gross domestic product per capita, TO – trade openness, EC – energy consumption, GLO – globalization, INI – investment intensity, INT – Internet, FDI – foreign direct investments, TR – total trade, INF – inflation, URB – urbanization, EL – electricity consumption, IND – industrialization, AR – aging rate, PD – population density, POPGR – population growth, PRW – proportion of women in total labour force, DEM – democracy, FD – financial development, INDS – industrial structure, INQ – institutional quality, POP – population, HD – human development, MAV – manufacture value-added, RL – rule of law. **Methodology**: ECM – Error Correction Model, ARDL – Autoregressive Distributed-lagged Model, VECM – Vector Error Correction Model, VAR – Vector Autoregression, GMM – Generalized Method of Moments, MG – Mean Group Estimator, AMG – Augmented Mean Group Estimator, PMG – Pooled Mean Group Estimator, CCEMG – Common Correlated Effects Mean Group Estimator, DOLS – Dynamic Ordinary Least Squares, FMOLS – Fully Modified Ordinary Least Squares. **Countries**: MENA – the Middle East and North Africa region, ASEAN – Association of Southeast Asian Nations, OECD – The Organisation for Economic Co-operation and Development, BRIC – Brazil, Russia, India and China.

CONCLUDING REMARKS

For a summary of the EKC research conducted for single countries, it can be concluded that studies have been carried out over different periods depending on available datasets. The majority of analyzed studies have used carbon dioxide (CO_2) or sulfur dioxide (SO_2) as a depended variable, while energy consumption, GDP, and square value of GDP were used as explanatory variables. Some authors used the set of explanatory variables as follows: trade liberalization, population density, financial development, trade openness, foreign direct investments, labour force, export, import, urbanization, foreign trade, environmental productivity, energy use, ecological footprint, coal consumption, control of corruption and governess, etc. In most of the studies dealing with EKC for single countries, the ARDL methodology is used. Additionally, in these studies, other panel techniques were utilized, such as Granger causality approach, VECM method, and cointegration approach.

Similarly, as in the single country case, studies conducted for a group of countries have been carried out over different periods, with a different set of input variables and various methodology frameworks. Almost all studies have used CO_2 emissions as the depended variable, while energy consumption, GDP and square value of GDP were used as explanatory variables in nearly all of the studies. Throughout time, the set of explanatory variables has been expanded towards considering trade openness, globalization, investment intensity, Internet, foreign direct investments, total trade, inflation, etc. If countries are considered and analyzed as a group, then researches applied a wide range of methodologies and advanced econometric models appropriate to considered panel dataset. In most cases, standard tests such as panel unit root tests, cointegration techniques and Granger causality were utilized. Given that variables are cointegrated, different estimators were used to estimating the relationship between variables. Due to the panel type of data, researchers tried to address the slope heterogeneity and cross-section dependence by considering panel data estimators such as AMG and CCEMG, that have shown advantages over MG. The other group of researchers used parametric DOLS and non-parametric FMOLS estimator to deal with bias by taking the leads and lags of the first-differenced independent variables. In addition to these estimators, researches also used a more advanced panel dynamic GMM to address autocorrelation and country-specific effects. An innovative approach in testing EKC includes panel smooth transition regression model as well as panel quantile regression model.

According to Asumadu-Sarkodie & Strezov (2019a), Lind & Mehlum (2010) claim that "the criteria are weak when "the true relationship is convex but monotone over relevant data values", as such, the quadratic specification produces erroneous turning point and U-shaped relationship." They further claim that to properly test the existence of a U-shape, "there is a need to test the decreasing relationship at low values within the interval values and the increasing relationship at high values within the same interval. Thus, when the relationship increases at the left-hand side of the interval and decreases at the right-hand side, the traditional method of U-shape estimation is not suitable." (Lind & Mehlum, 2010). They created an algorithm used to test the presence of the U-shaped, inverted U-shaped or monotonic relationship of the interval. U-test algorithm can be applied to the data range as an interval unless otherwise indicated (Asumadu-Sarkodie & Strezov, 2019a).

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