A Review of the Environment Kuznets' Curve Literature: Global Evidences and Policy Implication

Karabee Medhi

Assistant Professor, Department of Economics, Guwahati College

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ABSTRACT

The Environmental Kuznets Curve (EKC) hypothesis is an inverted U-shaped relationship between economic growth and environmental degradation. This review examines the evolution of EKC research worldwide and the policy implications of these studies for emerging economies. The main contributions of this study are the assessment of contradictory results on the validity of the EKC, evaluation of various research methodologies adopted in EKC research, focus on the impact of different institutional factors on the validity of the EKC, and analysis of regional differences. Mixed empirical evidence has been observed from the literature review, with results varying depending on the geographical area, pollutant type, and methodology. The review concludes that the EKC hypothesis is not universally applicable. Therefore, it is crucial to emphasize the importance of proactive governance, technological innovation, and targeted environmental protection for sustainable development. Further research is needed to explore broader environmental dimensions, compare institutional roles across regions, and examine the impact of globalization using advanced methodologies.

Keywords- Environmental Kuznets Curve (EKC), Economic growth, Environmental degradation, Sustainable development

INTRODUCTION

The relationship between economic growth and environmental quality has remained one of the most debated issues in environmental economics for decades. The Environmental Kuznets Curve (EKC) hypothesis, which describes the inverted U relationship between economic growth and the environment, has captured the attention of researchers, policymakers, and environmental advocates worldwide. This hypothesis states that environmental degradation increases in the initial stages of economic development but eventually decreases after reaching a certain income level (Grossman & Krueger, 1991; Panayotou, 1993). This inverted-U-shaped relationship suggests that economic growth can be a solution to environmental problems rather than just their cause, as countries can "grow first and clean later" after reaching a particular level of development.

The foundation of the EKC was derived from Simon Kuznets' inverted-U hypothesis between per capita income and income distribution (Kuznets, 1955). However, compared to the original Kuznets' curve, the environmental adaptation of this concept has proven to be much more complex and controversial. Building on the original Kuznets' curve, Grossman and Krueger (1995) provided a theoretical framework for the Environmental Kuznets' curve, where an inverted U relationship has been portrayed not between growth and inequality but between growth and environmental degradation. Following this, different researchers have studied the EKC hypothesis at different time periods across various countries and environmental indicators using different methodologies and indicators of environmental quality. This review examines the evolution of research on the EKC hypothesis from its theoretical origins to contemporary empirical developments. It attempts to place particular importance on the methodologies and policy implications for emerging economies. This review contributes to the literature in a number of ways. First, it provides a systematic assessment of various studies that have provided contradictory results on the validity of the EKC hypothesis. It also attempts to evaluate the shift in recent studies from conventional inverted U-shaped curves to U-shaped curves or more complex N-shaped patterns. Second, this study attempts to critically evaluate the different methodologies adopted in EKC research, the different types of pollutants used to represent environmental degradation, and

how the heterogeneity of the methodologies and selection of pollutants have impacted the empirical findings. Third, it examines the impact of various factors, such as institutional quality, technological innovation, and the use of renewable energy alternatives, on the EKC. Fourth, the study examines research studies across various regions, with special emphasis on India, focusing on geographical differences in findings and unique challenges and opportunities in balancing economic growth and environmental relationships. This review is expected to offer valuable insights to future empirical studies in this area and help frame sophisticated policy initiatives for environmental protection and economic growth in line with achieving sustainable development goals.

THEORETICAL BACKGROUND

The theoretical base for the EKC hypothesis can be traced back to Simon Kuznets's (1955) model of income inequality. This hypothesis shows that during the early stages of economic growth, income inequality rises. Thereafter, beyond a certain level, income inequality starts to fall, and thus the relationship between income and inequality takes the form of an inverted-U-shaped curve. The Environmental Kuznets' Curve postulates a similar inverted-U relationship between environmental degradation and the level of national income. Environmental pollution initially rises with economic growth and then starts to decline as income continues to rise (Dinda, 2004; Stern, 2004). During the early stages of industrialization and urbanization, environmental pollution intensifies due to increased exploitation of natural resources and prioritization of economic output over ecological concerns. Especially in underdeveloped economies, this trend is more prominent, with a primary focus on income growth and poverty reduction and limited priority investment in the environment. (Gill, Viswanathan, & Hassan, 2017; Asumadu-Sarkodie & Strezov, 2019a). At this stage, a positive relationship exists between economic growth and environmental degradation. With the progress of a nation, technological advancements and structural changes in the economy occur. This can lead to the disintegration of environmental degradation, which was associated with economic growth in the early stages.

The traditional EKC framework explains the inverted U relationship through three main effects: scale, composition, and technique (Grossman & Krueger, 1991). The scale effect states that as an economy starts to develop, production volume increases, and resource use and pollution emissions also increase, leading to a greater degree of environmental degradation. At lower income levels, nations cannot invest in advanced industrial technologies and depend on conventional industrial processes that are normally reliant on cheap fossil-fuel-based technologies. Therefore, the scale effect dominates at lower income levels, leading to an increase in pollution emissions in the initial stage of development. As the economy progresses and the transition from agriculture to industry and service sectors is experienced, the composition effect arises. These sectors are technology-driven and tend to be less polluting; therefore, the pressure on the environment is reduced once the composition effect comes into effect. The technique effect comes into operation once the economy reaches a certain level of development. Economic development brings sophisticated technologies and institutional regulations to increase resource efficiency and pollution control, thereby improving environmental quality at a higher stage of economic development. (Asumadu-Sarkodie & Strezov, 2019a; Panayotou, 1993; Owusu & Asumadu, 2016).

Although economic and technological factors play the most vital role in explaining the EKC pattern, institutional quality and policy frameworks are also critical factors affecting the growth-pollution relationship. For instance, improved governance and regulations accelerate the benefits of technological progress and promote sustainable consumption (Beckerman, 1992; Lapshina, Bakaeva, & Sotnikova). Trade openness may have both positive and negative impacts on the environment; it can increase pollution by expanding the production scale and fostering cleaner technologies and practices through composition and technique effects (Dinda, 2004).

Thus, the EKC serves as a conceptual framework that illustrates how environmental quality can initially deteriorate and later improve with economic development. The EKC framework can be regarded as the foundation of ongoing academic and policy discussions on sustainable development and the steps towards a green economy.

Empirical Evidence of EKC Hypothesis

Studies supporting EKC

Several studies provide evidence for the existence of the EKC hypothesis across countries at different time periods using different pollutants. Bibi and Jamil (2021) revealed that the EKC hypothesis is valid across global regions such as Latin America, East Asia, Europe, Central Asia, South Asia, and the Middle East and North Africa, but not in Sub-Saharan Africa. This study found evidence of regional heterogeneity in the EKC. Al-Rawashdeh et al. (2015) documented validity of EKC for SO_2 and CO_2 emissions in several MENA countries at the individual-nation level. Adeel-Farooq et al. (2020) confirmed the validity of the EKC for methane emissions in ASEAN countries. Özataç et al. (2017) and Ahmed and Long (2013) validated the EKC in Turkey and Pakistan, respectively, with long-run relationships between growth and CO_2 emissions in both countries. Adebayo (2020) established the EKC in Mexico for CO_2 emissions using a mix of time series econometric techniques. Saqib et al. (2022) found evidence of the existence of the EKC in the E-7 economies. Their study highlighted the influence of technological innovation, human development, and renewable energy on this pattern. Murshed (2020) found evidence of the EKC in Bangladesh by considering deforestation indicators. This study also confirmed that the quality of democracy can affect growth and environment relationship.

Several studies at the state or provincial level, such as Işık et al. (2019, 2021), show the existence of the EKC in selected US states. The study found evidence of policy-specific or region-specific turning points in this relationship. Thus, although EKC patterns have been observed in many empirical studies, the results are not uniform and often depend on specific economic, political, or structural factors.

Studies not supporting EKC

There are a good number of studies that provide strong evidence against the classical Inverted-U relationship. In contrast to the U-shaped association between growth and environmental quality, these studies opine in favor of a monotonic, U-shaped, or inconclusive relationship. Beyene (2022) undertook a global study using the Environmental Performance Index and found insignificant or inconsistent links between economic growth components and environmental quality. Dogan and Türkekul (2016) showed that GDP growth could improve environmental metrics in the USA, but the inclusion of quadratic terms (GDP^2) actually increased emissions, failing to support the EKC premise. Yilanci and Pata (2020) found no support for the EKC in China, where economic complexity and energy consumption have persistently worsened its ecological footprint. Seppälä et al. (2001) demonstrated that EKC patterns do not hold for aggregated material flows among industrialized nations. Koc and Bulus (2020) found an N-shaped relationship for South Korea, rejecting the inverted-U EKC. Chng (2019) did not find evidence for the EKC in Malaysia, the Philippines, or Indonesia, although it was present in some other ASEAN countries. Setiawan and Anwar (2022) reported an open U-shape for Indonesia, not an EKC. Ullah et al. (2021) and Villanthenkodath et al. (2021) documented U-shaped or alternative dynamics for Vietnam and India, respectively.

These studies highlight the fact that, in contrast to the optimistic views of the proponents of the EKC, the validity of the EKC is not uniform. Economic growth alone is often insufficient to guarantee environmental protection and improved environmental quality in the long run.

Beyond the Inverted-U: N-Shaped and Complex Relationships

Empirical investigations have increasingly moved beyond the simple inverted-U relationship, and many studies have revealed N-shaped, U-shaped, or even monotonic relationships. The N-shaped curves are characterized by environmental degradation initially rising with growth, then falling after a certain level of income, and then rising again at higher income levels. Allard et al. (2018), using panel quantile regression for 74 countries, found N-shaped EKC in all but upper-middle-income countries. Abbasi et al. (2023) and Jahanger et al. (2023) confirmed N-shaped (or inverted N-shaped) relationships in global and nuclear-energy producing country samples. Narcisse et al. (2023) and Bekun et al. (2021) observed N-shaped EKCs for China and Sub-Saharan Africa, indicating cyclical environmental pressures aligned with economic cycles and energy consumption.

Bandyopadhyay and Rej (2021) revealed an "inverted N-shape" for India in the context of nuclear energy deployment.

Certain studies, especially those on newer industrializing or lower-income countries, show a persistent or even accelerating upward trend of environmental impact with income, or an initial decline followed by later deterioration. Ullah et al. (2021) (Vietnam) and Villanthenkodath et al. (2021) (India) exemplify this trend. These findings caution against drawing conclusions on universally accepted outcomes of economic growth and emphasize the need for policy vigilance, even at higher income levels.

Impact of institutional and technological factors

Recent studies have shown the significance of institutional quality, governance, and technology adoption as crucial determinants of the EKC relationship. Al-Mulali et al. (2021) in their study found that government effectiveness was crucial for validity of the EKC. In countries with weak institutions, pollution and economic growth are not related. Murshed (2020) illustrated that democracy lowers the income threshold at which environmental improvements begin. Saqib et al. (2022) and Bekun et al. (2021) highlighted the roles of renewable energy and technological progress in reducing the emissions. Abbasi et al. (2023) found that renewable and nuclear energy alleviated pollution, especially in lower quantiles of their data. Yilanci and Pata (2020) observed rising economic complexity and fossil fuel dependency as drivers of increasing ecological footprints, despite economic development. Studies incorporating energy transitions, such as those for Turkey, Korea, and nuclear-rich nations, directly link energy composition to environmental outcomes. In summary, the attainment of the EKC pattern is dependent on country-specific institutional factors and the robustness of the policy frameworks across nations.

EKC studies by geographical area

Global and cross-country studies on the Environmental Kuznets Curve (EKC) reveal a heterogeneous picture. Empirical studies have shown that various institutional, structural, and regional characteristics of countries significantly impact the existence and validity of the EKC. For instance, Beyene (2022),in his study, used data from 108 countries and found that while scale and technique effects had role in environmental degradation, but significant EKC pattern was rarely observed. Bibi and Jamil (2021) conducted a cross-regional analysis and found positive evidence of the EKC in all regions under study, except for sub-Saharan Africa. Al-Mulali et al. (2021) used data of 170 nations and found that the EKC relationship could be validated only in countries with high or moderate levels of government effectiveness. The findings of this study highlight the influential role of political and institutional quality in the existence of the EKC. Saqib et al. (2022) in their study focused on E-7(Brazil, China, India, Indonesia, Russia, Mexico, and Turkey) emerging economies and confirmed the presence of the EKC. This study also highlighted the positive contributions of human development, renewable energy, and technological advancement in reducing emissions, thereby adding complexity to the growth-emission pattern. Moving to regional analyses, diversity becomes even more apparent in the literature. In the MENA region, Al-Rawashdeh et al. (2015) found the validity of the EKC only for certain pollutants and countries, while Bibi and Jamil (2021) highlighted intra-regional disparities. Studies in the Asia-Pacific region have displayed similar mixed results. Adeel-Farooq et al. (2020) find evidence of the EKC hypothesis for methane in ASEAN, while Chng (2019) shows that the pattern appears only in Singapore, Thailand, and Vietnam, but not in Malaysia, Indonesia, or the Philippines. Studies have revealed that China is highly pollutant-dependent. Xu (2018) and Yan et al. (2023) observed an inverted U shape for some pollutants in China. Yilanci and Pata (2020) dismiss the EKC altogether for ecological footprints due to rising complexity and energy use. For India, Sultan et al. (2021) support the EKC, advocating incremental change, whereas Korea (Koc & Bulus, 2020) demonstrates an N-shaped curve, and Vietnam (Ullah et al., 2021) and Indonesia (Setiawan & Anwar, 2022) show U-shaped or open U patterns, reflecting different stages of industrial development and energy dependency. In Africa, the role of democracy and natural resource management emerges from Murshed (2020), Tenaw and Beyene (2021), and Sarkodie (2018), who show that policy and demography are essential determinants. Latin American analyses (Seri & Fernandez, 2021) find EKC evidence only in a minority of countries, emphasizing policy and institutional importance, while European and North American cases demonstrate substantial heterogeneity even within nation-states. Mazzanti et al. (2007) point out sectoral and spatial variations in Italy, Işık et al. (2019, 2021) report both positive and negative evidence of

the EKC in US states, and Dogan and Türkekul (2016) and Seppälä et al. (2001) fail to support the EKC for the US as a whole. These studies validate the finding that the EKC hypothesis is not universally true, and geographical location influences the validity of the hypothesis.

India-Specific Evidence

Various studies conducted in India to test the EKC hypothesis show a complex relationship between growth and environmental quality. Bandyopadhyay and Rej (2021) found an inverted N-shaped EKC for India. They identified a critical inflection point in 2015. This is explained by changes in the behavior of emissions due to shifts in the government policy framework. Usman et al. (2019) in their study confirm the validity of EKC for India, highlighting weak influence of democracy on the environmental quality in the long run but a strong impact in the short run. Villanthenkodath et al. (2021) and Ullah et al. (2021) found that economic growth induces a U-shaped relationship with environmental degradation in India. Energy structure and population growth are the key drivers of this relationship. Rana and Sharma (2018) added further dimensions to the EKC literature of India. They observed that both the Pollution Haven Hypothesis and EKC were valid in India. Their study emphasized the roles of foreign direct investment (FDI) and international trade in shaping carbon emission patterns. These studies imply that there may be a valid EKC in India, but the actual shape of the curve is not necessarily inverted U, and structural and institutional factors affect the shape and validity of the EKC hypothesis in India.

EKC studies by pollutant/environmental indicator

Significant variation in the concluding evidence of EKC studies was observed depending on the environmental indicator. In the literature, carbon dioxide (CO_2) emissions are the most widely used pollutants, but the findings are mixed. For example, Ahmed and Long (2013) for Pakistan and Adebayo (2020) for Mexico found an inverted-U relationship between income and CO_2 emissions, supporting the Environmental Kuznets Curve (EKC) hypothesis. In contrast, research on Korea observes an N-shaped curve, and several studies in China report a monotonic increase in CO_2 emissions with rising income, indicating no EKC turning point (Yilanci and Pata, 2020). Methane (CH_4) and sulfur dioxide (SO_2) emissions are other commonly used indicators of environmental degradation. Adeel-Farooq et al. (2020) find evidence of an EKC in the ASEAN context, implying that economic growth can reduce certain greenhouse gas emissions under the right conditions. Sulfur dioxide (SO_2), a typical local pollutant, shows consistent inverted-U patterns in several MENA countries, as observed by Al-Rawashdeh et al. (2015). This study extends specific support to the validity of the EKC for pollutants that have localized impacts and regulatory policies and solutions. In contrast to these composite measures of environmental quality, such as Beyene ’s(2022) Environmental Performance Index (EPI), which provide only mixed or insignificant evidence for the EKC, Zhao et al. (2023) identified an EKC turning point for air pollution in Henan Province, China, around 2014. Murshed (2020) considered deforestation in Bangladesh as an indicator of environmental degradation and found support for the EKC. This study finds that this relationship is significantly influenced by democracy and governance quality. These findings indicate that the EKC is more likely to be valid for local pollutants than for global indicators such as CO_2, ecological footprints, and deforestation, and aggregate indices. In such cases, robust results are not observed, and the findings are more sensitive to specific contexts and institutional factors.

METHODOLOGICAL APPROACHES

Similar to other empirical studies, the findings in the Environmental Kuznets Curve (EKC) literature are significantly impacted by the methodologies adopted by the studies. The results of the studies are found to be largely sensitive to the research methodology adopted, such as the model and variable selection and econometric methodology. In cross-country studies of the EKC, panel econometric methods such as Augmented Mean Group (AMG), Pooled Mean Group (PMG), and Cross-Sectional Autoregressive Distributed Lag (CS-ARDL) are mostly used, as seen in studies such as Tenaw and Beyene (2021) and Saqib et al. (2022). These econometric tools are regarded as robust for addressing heterogeneity, cross-sectional dependence, and dynamics across countries. For country-specific studies, time-series models, including ARDL, VECM, and advanced forms such as Fourier-ARDL, are used. These studies provide important insights into the long- and short-run relationships between growth and emission. In some studies, composite models have been used, such

as the integration of the Armey curve with the EKC (Isik et al.,2021). Moreover, few studies have incorporated various structural and institutional factors, such as the impact of governance(Al-Mulali,2021), quality of democracy(Murshed,2020), economic volatility(Genc,2021) and sector-specific analysis, such as agriculture (Atasel et al., 2022), into the EKC, which has enabled an in-depth understanding of the diverse factors influencing the EKC pattern. It has been observed that EKC studies yield different results depending on the specific methodologies used; therefore, the conclusions cannot be regarded as universal realities but are specific to the framework, assumptions, and methodologies. Therefore, careful model selection, which best fits the data and specific context, is important for the practical applicability of the findings of the EKC research.

Research Gaps and Directions

A notable concentration of carbon dioxide as a pollutant has been observed in the EKC literature. Various other broader environmental dimensions, such as biodiversity loss, water quality, and land use changes, remain underexplored in the EKC literature and require a greater degree of research. Environmental degradation has multifaceted aspects, and evaluating the impact of growth on these aspects is crucial for a true assessment of sustainability issues and challenges. Researches have observed that institutional factors, such as government quality and democratic processes influence the validity of EKC, but their comparative roles across different regions is another vital area that requires deeper research. Large-scale meta-analytical studies can provide fruitful insights into the significant heterogeneity in EKC studies to draw consistent findings. Furthermore, there is a need for increased use of advanced methodologies, such as studies considering structural breaks, nonlinear patterns, and causal interferences, which would add significant value to the literature. Finally, there is a complex role of international trade and globalization on pollution as it is a global phenomenon and constitutes a crucial area for future research that is not sufficiently explored in the existing literature. Addressing these research gaps is crucial for further enriching the EKC literature, which can assist policymakers in understanding the complexity of the EKC for better policy formation.

CONCLUSION

The present review analysis of the Environmental Kuznets Curve (EKC) indicates that this hypothesis is not universally applicable to all pollutants, countries, or developmental contexts. Although the traditional inverted U-shaped relationship between economic growth and environmental degradation is observed for certain pollutants, primarily localized ones such as sulfur dioxide as well as specific contexts, such as some developed nations, there is no consistent evidence of the pattern across all studies. The EKC validity is significantly affected by the type of pollutant considered in the study, along with other factors such as institutional capacity, quality of governance, quality of democracy, methodology, and the research's analytical framework. The diverse findings on the relationship between growth and environmental degradation, such as the N-shaped and monotonic relationships, have important policy implications. These findings pose a serious threat to the conventional thesis of "grow now, clean later" and call for serious reconsideration. To ensure sustainable development, countries require proactive governance, technological innovation for efficient energy use, and the integration of renewable energy and targeted environmental protection from the early stages of development. Strategies to balance development with environmental protection should be according to the context and realities of the particular economy. This approach requires structural reforms, strengthening institutions within nations, and working together on a global platform to manage the cross-border pollution. Further research in this area beyond carbon-centric analyses, with the inclusion of diverse ecological indicators, advanced methodologies to capture nonlinearities and structural shifts, and cross-country comparative studies will ultimately advance the understanding of the EKC and the complexities of economic growth and environmental degradation. This can guide policymakers in framing appropriate country and context-specific policies to balance growth and environmental sustainability.

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