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RE-EXAMINING THE ENVIRONMENTAL KUZNETS CURVE HYPOTHESIS IN EMERGING ECONOMIES: THE MITIGATING ROLE OF TRADE OPENNESS AND RENEWABLE ENERGY[1]

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ABSTRACT

This review surveys the influence of economic growth, trade openness, and energy consumption on environmental pollution (specifically, CO2 emissions) within a group of developing economies. The sample consists of 37 countries classified as upper-middle-income developing economies by the World Bank, covering the period from 2000 to 2023. The estimations were conducted via the Parks-Kmenta Feasible Generalized Least Squares (FGLS) method. The evidences remark that a 1% rise in economic growth (GDP) leads to a 2.71% rise in CO2 emissions. This affair persists up to a certain threshold; initially, economic growth degrades environmental quality. However, this process lastly peaks, reaching a turning point where the affair inverts in later stages of development. Beyond this turning point, a 1% rise in economic growth (represented by the squared GDP term) diminishes CO2 emissions by 0.16%. In other words, as wealth improves beyond a specific income level, greater emphasis is placed on environmental quality, leading to a reduction in pollution. Regarding other variables, a 1% rise in energy use (ENG) boosts CO2 emissions by 1.73%. Conversely, a 1% rise in trade openness (TRD) diminishes emissions by 2.08%, and a 1% rise in renewable energy consumption (REW) leads to a 0.17% reduction in emissions. Urban population density (URB), included as a control variable, is found to rise CO2 emissions by 1.06% for every 1% increment. An analysis of the variables discloses that the primary driver of environmental degradation is the economic growth efforts of countries at lower income levels (GDP impact: 2.71%). Besides, the calculated turning point for the studied countries is $3,077 per capita. This purports that environmental pollution rises until per capita income reaches $3,077, peaks at this level, and afterwards, the influence of economic growth on pollution shifts from positive to negative.

KEYWORDS: Economic Growth, Environmental Sustainability, Foreign Trade, Renewable Energy, Urbanization.

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1. INTRODUCTION

Since the Industrial Revolution, a significant turning point in world economic history, humankind has struggled for economic development while meanwhile facing the environmental costs of these processes. The usage of fossil fuels for energy, a basic input for industry, and the following unbounded industrialization have led to the outbreak of varied environmental issues. The issue of greenhouse gas accumulation in the atmosphere has turn out progressively crucial. Thence, global warming and climate change have taken their place on national agendas, transforming from a purely environmental problem into a hazard to humankind. According to the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6), when comparing the pre- and post-industrial periods, global surface heats have arisen by 1.1°C since industrialization. Besides, the report specifies that if no action is taken, this number could overrun 1.5°C. This temperature is the target set by countries under the Paris Agreement, and the report specifies that failure to take action could result in temperatures far exceeding these targets (IPCC, 2023:70-77). Developing countries, which concluded their industrialization process at an afterwards stage than developed countries, must take into account environmental sustainability while accomplishing their economic growth goals. Within the framework of the United Nations Sustainable Development Goals (SDGs), developing countries require to both expand their economic growth rates and advance their living standards (SDG 8), while also not disregarding climate action (SDG 13) and the transition to clean energy (SDG 7) (United Nations, 2024:42). From this view, economic growth and environmental sustainability are betwixt the most debated matters from a macroeconomic point of view, and many researches are being conducted on them. Developing countries, in order to reach the level of developed countries, are carrying a speedy industrialization transformation, and their energy needs are enhancing significantly as an outcome of this increased industrialization process.

A long-standing argument in economic literature concerns whether countries' economic growth efforts pollute the environment, or whether, after a precise income level, economic growth purifies rather than pollutes it. Analysing the theoretical background of economic growth and the environment, the first thing that comes to mind is the Environmental Kuznets Curve (EKC) hypothesis, first mentioned by Grossman and Krueger (1991) and further developed by Kuznets (1995). According to the Environmental Kuznets Hypothesis, when a country participates a period of economic development, industrialization improves, leading to a significant increment in resource usage. Hereby, an increment in environmental pollution, i.e., CO2 emissions, is anticipated. The first stage of the Environmental Kuznets Hypothesis is categorized in the literature as the "scale effect." Over time, as countries reach a precise milestone in their per capita national income, environmental awareness elevates within society, improvements are made in environmental areas, a shift takes place from industry-intensive sectors to service-intensive sectors, and the usage of clean technologies that do not pollute the environment or have a more micro-level influence becomes pervasive. As a result of this transformation, the influence of economic growth on the environment commences to shift from negative to positive; that is, economic growth shifts from polluting the environment to cleaning it up. This stage is called the structural (composition) and technical (technique) influence. Hereby, a non-linear, inverted U-shaped relation is monitored betwixt economic growth and environmental pollution. Even though the Environmental Kuznets Curve sustains its stature in the theoretical background, complete consensus has not been reached in the literature on this matter. There is surveyor who acquire different outcomes for developing countries. Herewith, it is necessary to re-examine the Environmental Kuznets Curve for developing countries with the most up-to-date data and robust econometric methods.

When perusing environmental pollution (CO2 emissions), it is prominent to recall that numerous factors, along with economic growth, can be determinative in determining CO2 emissions. Countries' energy consumption patterns and foreign trade conditions are also anticipated to impress CO2 emissions. Countries have historically used fossil fuels as their fundamental energy source to accomplish their economic growth goals. However, fossil fuels are also one of the major causes of environmental pollution, i.e., CO2 emissions. Nonetheless, in recent years, there has been a boosted shift towards renewable energy sources such as solar, wind, and hydroelectric power due to diverse motives. This is a prominent development with the potential to diminish CO2 emissions in the atmosphere (Dogan and Seker, 2016:429-430). Besides, foreign trade is another macroeconomic matter discussed in relation to environmental pollution. In the literature, the argument surrounding the pollution haven hypothesis—that developed countries, when trading with developing countries, do so to avoid polluting their own countries or to bypass strict environmental regulations, thus transferring pollution there—is discussed (Copeland and Taylor, 2004:9). However, another disputed topic, within the framework of the pollution halo hypothesis, is that developed countries, when funding in and trading with developing countries, also bring along environmentally friendly advanced technologies, thereby facilitating the decline of CO2 emissions (Antweiler, Copeland, and Taylor, 2001:877-880). In addition, the speedy increment in urbanization rates in developing countries can compose energy intensity and accelerate environmental dynamics (Nathaniel, Anyanwu, and Shah, 2020:14601-14602).

While the literature discloses countless studies surveying the Environmental Kuznets Curve (EKC) hypothesis for diverse countries, this survey is anticipated to stand out due to its original contribution to the literature. First of all, this survey covers 37 developing countries classified as upper-middle income by the World Bank. A few of other countries could not be included due to data limitations. Besides, the period 2000-2023 cover a prominent timeframe where the influence of numerous global climate agreements can be observed, renewable energy trends gain prominence, and numerous changes occur in the dynamics of world trade. Methodologically, the survey operating a robust method like the Parks-Kmenta Flexible Generalized Least Squares (FGLS) estimator, which is robust to cross-sectional dependence and heteroscedasticity troubles. Another characteristic of this method is its ability to generate more coherent and neutral outcomes compared to many standard panel estimators. One of the most prominent and distinctive features of the survey is the calculation of a specific "turning point" for each country studied. This information is quite remarkable in terms of policy implications.

The empirical outcomes of the survey disclosed that the EKC hypothesis is prevailing for 37 upper-middle-income developing countries. While CO2 emissions enhance by 2.71% in the initial stages of economic growth, exhibiting a polluting effect, this reverses after a certain turning point, forming an inverted U shape. Alias, it commences to depurate the environment. A Wald test was conducted to definitely specify this turning point, identifying it as the point where GDP per capita reaches $3,077. Based on these outcomes, it was understood that countries in the upper-middle-income group, such as Türkiye, Brazil, China, and Mexico, have already overrun this threshold and entered the stage where economic growth depurates the environment. Yet, there are also countries in the group that are still in the stage where economic growth pollutes the environment, or have only recently passed this stage. Besides, the survey showed that trade openness and renewable energy are factors that diminish CO2 emissions, while urbanization, the control variable of the survey, is a factor that expands CO2 emissions. This status also discloses that developing countries can attain this turning point faster by focusing on foreign trade and renewable energy, thus evasion the need to pollute the environment first and then clean it up.

The remainder of the survey consists of a literature review in the second section. The third section summing up the theoretical framework of the pollution haven hypothesis, the pollution halo hypothesis, and the environmental Kuznets hypothesis. The fourth section details the Parks-Kmenta methodology, disputing empirical outcomes and milestone calculations. The final section submits the conclusions, discussion, and policy implications.

2. THEORETICAL BACKGROUND

When testing the economic factors impressing the pollution level, or quality, of a country's environment, it is monitored that they principally actuate within the framework of economic growth and free international trade, which are fundamental macroeconomic factors. The empirical analysis of the variables in this survey is based on three hypotheses in theory. The first is the Environmental Kuznets Curve (EKC), which declares that there is no linear relation betwixt a country's economic growth and environmental quality. In addition to this hypothesis, there are two opposed hypotheses explaining the relation betwixt free international trade and environmental quality. One is the Pollution Haven Hypothesis (PHH), which declares that free international trade generates environmental pollution, and the other is the Pollution Halo Hypothesis, which declares that free international trade diminishes environmental pollution by facilitating the convey of pure technologies.

To first clarify the relation betwixt economic growth and environmental quality, it is essential to peruse the work of Simon Kuznets (1955), the first remarkable survey on this issue. In his study, Kuznets (1955) clarified the relation betwixt income inequality and economic growth and emphasized that there is an inverted U-shaped relation betwixt them. Later, Grossman and Krueger (1991) reshaped this relation to adapt it to environmental economics, and the Environmental Kuznets Curve Hypothesis, which contains the inverted U-shaped relation, was born. According to this hypothesis, economic growth initially pollutes the environment and degrades environmental quality, and pollution enlarges as income levels rise. Later, this status attains a peak. This peak is called the turning point. After the turning point, economic growth has the opposite influence and has a declining influence on environmental pollution. Thus, an inverted U-shape comes in sight in the graphs. The Environmental Kuznets Curve and the inverted U-shape can be seen in Figure 1.

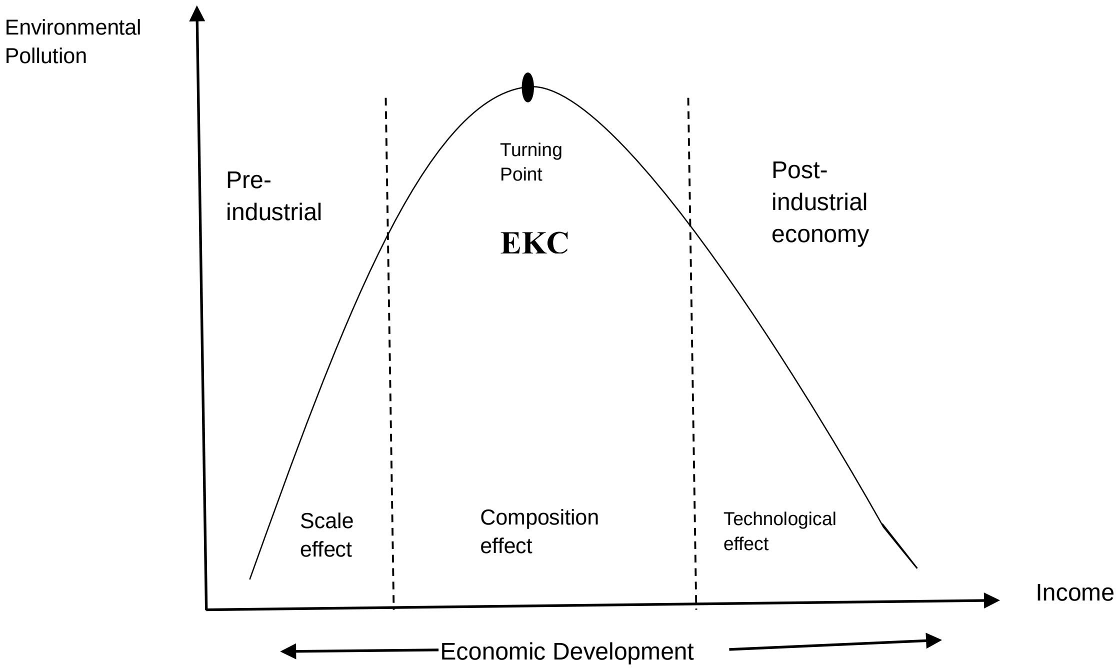

Figure 1: Environmental Kuznets Curve (Ekc)
(Source: Oladunni Et. Al., 2024).

As shown in Figure 1, the Environmental Kuznets Curve arise from three main effects. The first is the Scale Effect. This is the pretty beginning stages of economic development. During this period, there are increments in production and economic growth. Yet, these economic growth efforts lead to expanded usage of natural resources and leave behind more polluting waste. When more production is achieved with the existing technology and production structure, and if there are no changes in these variables, more production purports more environmental pollution. The economy then transitions to the stage where the Structural Effect (Composition Effect) becomes visible and come close to the turning point. In this stage, as economic growth comes about, the production structure of the existing economy gradually shifts from a fossil fuel-intensive and polluting heavy industry structure to a service sector that requires less polluting energy and has upward of income potential. A structural transformation process commences in the economy. As a result of these structural effects, the oppression on environmental pollution eases. After the turning point and the peak are reached, a decline in negative environmental influences commences to be observed. After these stages, the economy begins to fall under the Technological Effect. The curve commences to turn downwards. Economic growth and income boost at this stage lead to the introduction of new technologies that are less harmful to the environment, and increase R&D investments in areas such as renewable energy transition processes. Thus, while efficiencies in production processes enhances, environmental pollution begins to diminish (Stern, 2004:1419-1422). The principal question of this survey is when and at what income level the environmental degradation resulting from economies of scale can be remedied as a result of the technical and structural effects mentioned here.

After the 1980s, open-door policies commenced to be preferential worldwide, and globalization trends accelerated after the 1990s. Countries commenced to liberalize their foreign trade policies. These developments also brought about some alterations in environmental issues. In the literature, the influence of free foreign trade on the environment is examined under two main headings. The first of these is the

Pollution Haven Hypothesis. This hypothesis was first put forward by Copeland and Taylor (1994). According to this, international trade also leads to an exchange in terms of environmental pollution. Environmental awareness is upward of in developed countries. This cause to the inclusion of strict rules and regulations regarding the environment in laws and regulations. In these countries, it causes some additional costs, particularly to industries referred to as polluting industries such as iron, steel, and chemicals. These expenses are called environmental compliance costs. Accordingly, it can be a factor that enlarges the costs of these industries to manufacture in a country with strict environmental regulations. On the other hand, environmental rules may be more loose and environmental awareness may be more limited in less developed or developing countries. This status can improve naturally or be deliberately created by governments to attract investment. The gap in environmental costs betwixt developed and developing countries can lead to "dirty industries" shifting their production to developing countries to diminish expenses, thus polluting those countries. Consequently, countries with lax environmental legislations become a "refuge" for polluting industries, attracting foreign investment. Accordingly, studies on trade openness and environmental pollution in these countries will demonstrate that trade openness increases environmental pollution. In countries where the Pollution Haven Hypothesis is prevailing, a positive relation betwixt trade and CO2 emissions is expected.

The literature also includes a hypothesis arguing for a negative relation betwixt free international trade and CO2 emissions. This hypothesis is the Pollution Halo Hypothesis (Zarsky, 1999:54-55). Rather, this hypothesis proposes that foreign investments do not enlarges environmental pollution in developing countries, but rather generate chance for them to achieve a cleaner environment. According to this hypothesis, multinational corporations (MNCs) possess high-tech and cleaner energy-consuming capabilities, and they conduct their environmentally friendly capabilities and principles to the developing countries where they invest. Thus, a technology transfer takes place towards the developing country. Owing to trade openness, developing countries become acquainted with high-efficiency machinery and equipment, and their renewable energy technologies enable local firms to experience cleaner production processes (Birdsall and Wheeler, 1993:147).

This survey finalizes that the Pollution Hale Hypothesis is prevailing and that trade openness diminishes environmental pollution. Besides, findings promote the validity of the EKC (Environmental Conversion Hypothesis). These outcomes demonstrate that the technical (structural) effect, as seen in Figure 1, outweighs the scale effect. Further, when developing countries tend towards liberalization in their foreign trade policies, they acquire access to environmentally friendly technologies through technology spillover and can approach the EKC turning point more rapidly.

3. LITERATURE REVIEW

Investigation on environmental pollution, especially in the last thirty years, is characterized by its drastic adherence to the Environmental Kuznets Curve (EKC). Surveys examining the relation betwixt economic growth and environmental pollution can alter depending on the time period used, the selected country group, the methodology employed, and the dependent and independent variables included in the model. This section synthesizes surveys encompassing theoretical and empirical discussions in this field under four main headings. The first is studies perusing the relation betwixt economic growth and the ECC hypothesis. The others are, respectively, energy consumption and CO2 emissions, trade openness and the Pollution Haven Hypothesis, and finally, urbanization and environmental quality.

Initially, surveys investigating the relation betwixt economic growth and environmental quality led to the creation of the environmental literature surrounding the Environmental Kuznets Curve hypothesis. This hypothesis was acquainted to the literature by Grossman and Krueger (1991) and named the "Environmental Kuznets Curve" by Panayotou (1993). The Environmental Kuznets Hypothesis (ECH) demonstrates that when a country experiences economic growth and income levels increase, it initially aggravates environmental degradation, i.e., pollutes the environment. This is referred to as the scale effect. Afterwards, it is stated that technological progress begins when income levels reach a certain point, and this is referred the technical effect. Moreover, the shift towards cleaner energy sources and the development of environmental awareness in society cause to a diminish in environmental protection, which is described as a structural effect. In countries where the subject has developed, studies on the ECH hypothesis are present in the literature. In their research, which involved a detailed literature review, Shahbaz and Sinha (2019) stated that the type of EKC

(Economic Transformation) developed is most dependent on quality and efficient energy production within the organization. Apergis and Öztürk (2015) also surveyed EKC hypotheses for 14 Asian countries. In these surveys, they specified the existence of EKC using the Generalized Method of Moments (GMM) and emphasized that long-term economic growth cleans the environment and diminishes CO2 emissions. The authors calculated turning points, alike to their own experiences with these losses, and determined these turning points to be betwixt $1,000 and $15,000 depending on the level of development of the countries. There are also surveys that do not fully promote the characteristics that confront the EKC hypotheses. While some surveys in the literature completely refuse the EKC hypothesis and defend its validity, others argue that it is not U-shaped but N-shaped. Al-Mulali et al. (2015) can be cited as an example of this. The author's survey focused on Vietnam and demonstrated that economic growth increased with the ban, proposing that Vietnam has not yet reached a turning point. Another researcher, Allard et al. (2018), demonstrated an N-shaped relation betwixt economic growth and environmental pollution. The author executed an analysis across a wide range of countries, including 74. Their outcomes demonstrate an N-shaped relation betwixt the variables, meaning that reports diminished before the ban, then enlarged as income levels reached a certain height. Accordingly, the lack of consensus in the literature highlights the increasing need to identify a turning point for developing countries.

When examining the energy consumption structure and combinations of countries, it is observed that fossil fuels are heavily reliant on them. Therefore, there is a significant relationship between energy consumption and CO2 emissions. Sarkodie and Strezov (2019) state in their study that economies that consume and produce energy primarily from fossil fuels significantly increase environmental pollution. Nevertheless, environmental awareness has expanded globally, and a transformation process from fossil fuels to renewable energy sources has begun. Renewable energy sources are referred to as clean energy in the literature and conduce to the decline of environmental pollution. Dogan and Seker (2016) acquired outcomes promoting this status in their survey on EU countries. Balsalobre-Lorente et al. (2018), in their survey, included five EU countries and revealed that renewable energy conduces to the environment and forms an acceleration towards the turning point of the EKC hypothesis. Yao et al. (2019), in a similar survey carried out particularly on BRICS and Next 11 countries, found that as technology usage raises in these countries, the environmental cleaning consequence of renewable energy also increases. Their survey stated that diversifying the sources of energy consumed by countries is vital for both energy security and achieving global climate goals. Balsalobre-Lorente et al. (2018), in their survey, included five EU countries and unveiled that renewable energy contributes to the environment and initiates an acceleration towards the turning point of the EKC hypothesis. Yao et al. (2019), in a alike survey carried out specifically on BRICS and Next 11 countries, found that as technology use expands in these countries, the environmental cleaning influence of renewable energy also increases. Their survey stated that diversifying the sources of energy consumed by countries is vital for both energy security and achieving global climate goals.

An evaluation of studies in the literature examining the environmental impression of trade openness uncovers two highly debated hypotheses: the Pollution Haven Hypothesis and the Pollution Halo Hypothesis. The Pollution Haven Hypothesis asserts that as a result of free trade, developed countries transfer their production to developing countries, bringing pollution with them, thus increasing environmental pollution (Copeland and Taylor, 2004:9). The Pollution Halo Hypothesis, contrastingly, promotes that free trade facilitates to environmental quality through factors of endowment and technology diffusion. Based on this hypothesis, developed countries, while engaging in free trade with developing countries, also convey their high and clean technologies, giving rise to a diminution in environmental pollution in those countries. Antweiler et al. (2001) promoted this view in their survey, demonstrating that free trade giving rise to more streamlined usage of resources and the transfer of clean technology. While Destek et al. (2018) deduced that this status does not administer to middle-income developing countries, conversely, Shahbaz et al. (2017) stated that energy-efficient technologies are imported more frequently by means of free trade, thereby reducing environmental pollution. Alola et al. (2019) are also amongst the researchers who stated that countries have more convenient access to environmentally friendly and efficient technologies by means of trade openness.

In the literature examining the strain of abrupt urbanization on the environment, Nathaniel et al. (2020) pointed out that abrupt urbanization expands energy demands and intensity, which in turn increases environmental pollution. Examining the theoretical background on this matter, theories promote that urbanization may at first enlarges resource consumption and thereby increase environmental pollution, ultimately, due to factors such as the salience of the service sector and the increased use of public transportation as opposed to private vehicles in cities, environmental pollution may decrease (Poumanyvong and Kaneko, 2010:434-435). Nonetheless, this theory was not confirmed by Martinez-Zarzoso and Maruotti (2011). In their survey, the authors examined developing countries in terms of fast urbanization and environmental quality and emphasized that spontaneous urbanization has a vital polluting effect on the environment and that urbanization increases environmental pollution.

A scrutiny of the literature related to this survey disclose several deficiencies. Firstly, there is no consensus on the status of the EKC hypothesis particularly for developing countries. Moreover, the question of what constitutes the turning point that adjusted the environmental trajectory of these countries also manifests debatable. Alongside, an examination of the empirical aspects of existing surveys unveils the use of first-generation estimators that do not eliminate or consider standard deviations such as cross-sectional dependence and heteroscedasticity, which are common in panel data analysis. Nevertheless, using second-generation estimators in the presence of such standard deviations is vital for strengthening the validity of the outcomes. Besides, studies covering the period after 2020, including the recovery of global markets following COVID-19 and the recent energy crises, are pretty limited. One of the purposes of this survey is to fill these gaps in the literature. Firstly, this survey uses the most up-to-date dataset covering the period from 2000 to 2023 and incorporates global dynamics into its analysis. To tackle the empirical deficiency, the Parks-Kmenta Flexible Generalized Least Squares (FGLS) estimator was preferred, and the empirical portion was strengthened by considering the aforementioned standard deviations. One of the most vital contributions is the calculation of a net turning point ($3,077) for 37 developing countries, in addition to the positive environmental influence of trade openness and renewable energy. This can render as a reference point for these countries during their development phases.

4. DATA AND ECONOMETRIC METHODOLOGY

This chapter of the survey offers the empirical analysis conducted to test the relation betwixt variables, the dataset used, the definitions of the variables, the specification of the econometric model, and the theoretical basis of the Parks-Kmenta Flexible Generalized Least Squares (FGLS) estimator preferred as the method. The survey comprises 37 countries classified as upper-middle income by the World Bank. These countries are Albania, Algeria, Argentina, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Botswana, Brazil, China, Colombia, Cuba, Dominican Republic, Ecuador, El Salvador, Equatorial Guinea, Gabon, Georgia, Guatemala, Indonesia, Iran, Islamic Republic, Iraq, Kazakhstan, Libya, Malaysia, Mauritius, Mexico, Moldova, Mongolia, North Macedonia, Paraguay, Peru, South Africa, Thailand, Türkiye, Turkmenistan, and Ukraine. A few countries remaining in the classification were exempt in the survey due to data limitations. The survey period covers the years 2000-2023. Besides, panel data analyses were conducted using the STATA17 program. Table 1 shows the dependent and independent variables included in the survey. All data for these variables were compiled from the World Bank Development Indicators (WDI) database. Per capita CO2 emissions in metric tons were used as the dependent variable. The independent variables were determined in a way suitable for testing the Environmental Kuznets Curve. Table 1 includes all variables, their abbreviations, and explanations as used in the survey.

Table 1: Variables o the Survey.

Variable Type and Abbreviation	Variable Name
Dependent (Y)-CO2	CO2 Emissions (metric tons per capita)
Independent (X1)- GDP	GDP per capita (Constant 2015 US$)
Independent (X2)-GDP2	Square of GDP per capita (Constant 2015 US$)
Independent (X3)- ENG	Energy Use (kg of oil equivalent per capita)
Independent (X4)- TRD	Trade (% of GDP)
Independent (X5)- REW	Renewable energy consumption (% of total)
Control (X6) - URB	Urban population (% of total population)

So that test the validity of the EKC hypothesis and to decide the influence of other explanatory variables on the environment, a logarithmic-linear model was established and is shown in Equation 1. The cause for applying a logarithmic transformation to the variables is to stabilize the variance of the series.

$$\ln(CO2)_{it} = \alpha_0+\beta_1\ln(GDP)_{it} + \beta_2\ln(GDP)2_{it} + \beta_3\ln(ENG)_{it} + \beta_4\ln(TRD)_{it}+ \beta_5\ln(REW)_{it}+ \beta_6\ln(URB)_{it}\ \mu_i+\lambda_t+\varepsilon_{it} \quad (1)$$

i=1…37

t=2000-2023

Herein, i depicts countries (1...37), t depicts the period range (2000-2023), α_0 is the constant term, μ_i depicts country-specific effects, λ_t depicts time effects, and ε_{it} depicts the error term. For the EKC hypothesis to exist, the coefficient of economic growth, β_1, must be positive, and its square, β_2, must be negative, and this outcome must be statistically significant. That is, $\beta_1 > 0$, $\beta_2 < 0$. When this outcome is achieved, the inverted U-shaped relation mentioned in EKC is disclosed. This specifies that income increases resulting from economic growth at first increase environmental pollution, afterwards attain a turning point where it starts to diminish. Before estimating the data for the variables in the survey, a series of preliminary descriptive tests must be performed to figure out which estimator should be preferred. The estimator is determined based on these tests and the outcomes obtained. Table 2 shows the preliminary descriptive tests and their findings that aid in estimator selection.

Table 2: Preliminary Descriptive Tests Performed and Findings.

Test Type	Test Name	p-value	Result
Cross-Section Dependency	Pesaran CD	log_CO2:0.0000 log_GDP:0.0000 log_GDP²:0.0000 log_ENG:0.0000 log_TRD:0.0000 REW: 0.0000 log_URB:0.0000	There is cross-sectional dependence. Second-generation panel unit root analysis must be used.
Homogeneity	Swamy S	Prob>chi²: 0.0000	Since the parameters vary from unit to unit, heterogeneous cointegration tests should be used.
LagLength Selection	Hansen J	1 lag	The appropriate lag length is 1.
Unit Root	Im, Pesaran and Shin (CIPS)	P-Values dlog_CO2: 0.000 dlog_GDP: 0.000 dlog_GDP²: 0.000 dlog_ENG: 0.000 dlog_TRD: 0.000 d2_log_REW:0.000 d2_log_URB:0.000	The CO2, GDP, GDP², ENG, TRD variables is stationary at the first difference. The REW and URB variables becomes stationary after taking the second difference.
Unit Effect	F, LM, LR test	0.000	There is a unit effect.
Time Effect	F, LM, LR test	1.000	There is not a time effect.
Robust Hausman	rH test	0.8389	A random effects model must be used.
Multicollinearity	Variance inflation factor (VIF)	Mean VIF=1.53	No multicollinearity
Normal Distribution	Jarque-Bera	Test=57.7 Chi2= 2.9e-13 r(skewness):0. 6159 r(kurtosis): 3.334	There is a normal distribution. The error terms are slightly skewed and peaked to the right.
Autocorrelation	Durbin- Watson Baltagi-Wu, LBI	0.2454 0.4685	There is autocorrelation.
Heteroscedasticity	Levene, Brown and Forsythe Test	W0: Pr>F= 0.0000 W50: Pr>F= 0.0000 W10: Pr>F= 0.0000	There is heteroscedasticity.

As indicate in Table 2, cross-sectional dependence and homogeneity of parameters were tested for the series. Since the world is in a global process, it is strongly anticipated that an economic or environmental shock in one country will touch other countries as well. Accordingly, cross-sectional dependence is found in the series, and the parameters alter from unit to unit. This outcome specifies that second-generation unit root tests must be conduct. Except for REW and URB, the other variables become stationary after the first difference is taken [I(1)]. REW and URB, whereas, only become stationary after the second difference is taken [I(2)]. Since structural breaks can be observed in URB and REW data in developing countries, stationarization may take time. Yet, the model outcomes are dependable because the estimator used corrects the structure of the error terms. While there is a unit effect in the series, there is no time effect. In addition, the Robust Hausman test outcome demonstrates that the Random Effects model is more appropriate for this survey. Besides, according to the outcomes of the tests applied to the residuals of the model, there is no high correlation betwixt the variables. The error terms are slightly skewed to the right and flattened. Yet, it can be said that there is a normal distribution. But two principal problems were identified in structural prior tests. One of these is autocorrelation, and the other is heteroscedasticity. Under these circumstances, when cross-sectional dependence, autocorrelation, and heteroscedasticity problems are uncovered, standard OLS or random effects estimators cannot be preferred. There is a requirement for robust estimators that can correct for these standard deviations and ensure dependable and logical outcomes in the presence of these problems. Herewith, the Parks-Kmenta Flexible Generalized Least Squares (FGLS) estimator, which can adjust for all these problems, was preferred as the analysis method.

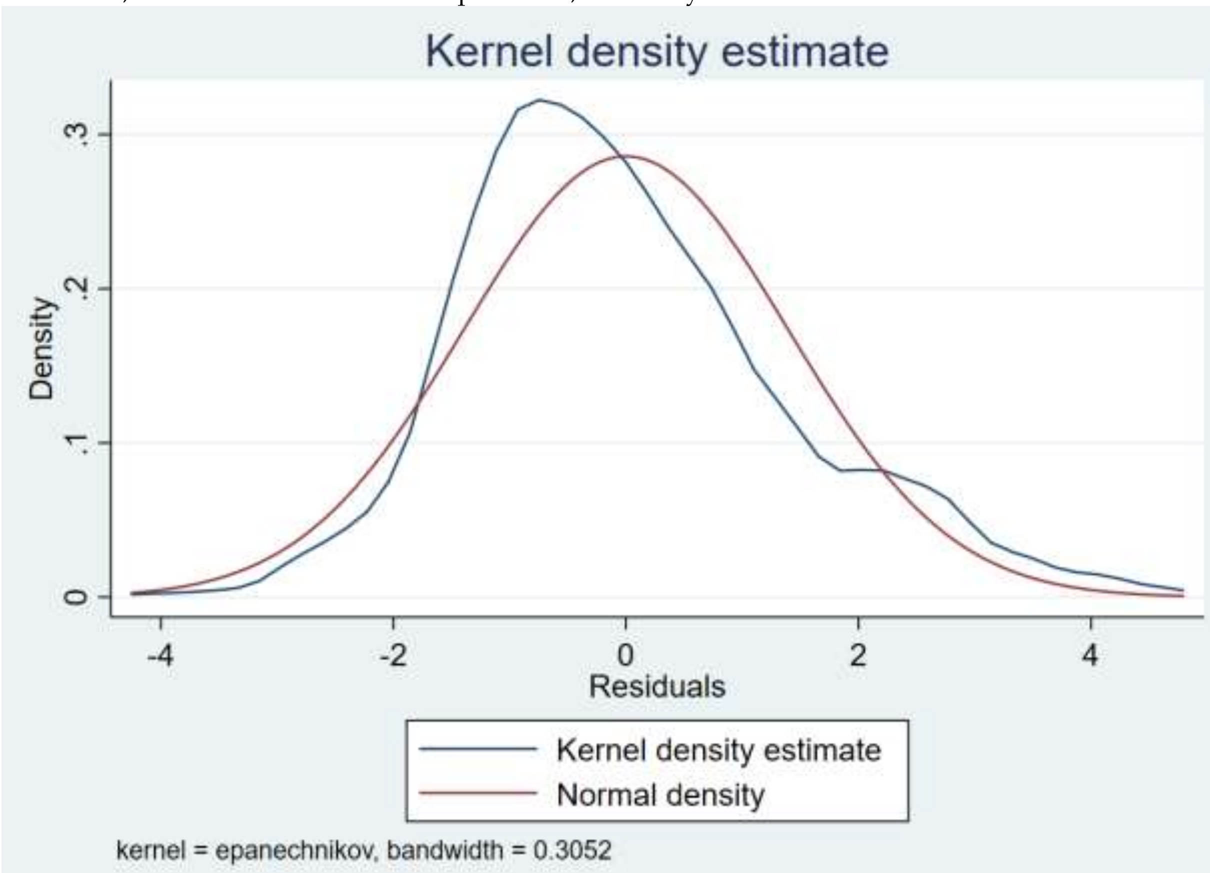

Figure 2: Graph Of Normal Distribution of Residuals.

Figure 2 demonstrates the graph of the normality test performed. It can be seen that the residuals are slightly skewed to the right and flattened, but still comply a normal distribution. In panel data analysis, the consistence of estimators be liable to significantly the error terms. Data sets for developing countries most of time come with three main problems: heteroscedasticity, cross-sectional dependence, and serial correlation, which were also bring to light in this data set (Baltagi, 2005). Standard Least Squares (OLS) and fixed effects (FE) estimators are not appropriate for usage in this status. Accordingly, to acquire more coherent and dependable coefficients, the Feasible Generalized Least Squares (FGLS) estimator, developed by Parks (1967) and extended by Kmenta (1986), was preferred in this survey. This estimator calculates the structure of the covariance matrix of the error terms and then implements the generalized least squares method. Table 3 demonstrates the predictions made using this estimator.

Table 3: Model Estimation and Empirical Findings.

Parks-Kmenta Feasible Generalized Least Square Estimator	**Number of Obs: 887**
	Number of Groups: 37
	Wald chi(6):3307.63
	Prob>chi: 0.000

log_CO2	**Coeffiecient**	**P>ll zll**
log_GDP	2.7154	0.065
log_GDP2	-0.1690	0.053
log_ENG	1.7369	0.000
log_TRD	-2.080	0.000
log_REW	-0.171	0.000
log_URD	1.0679	0.000
_cons	-14.8245	0.018

According to the outcomes in Table 3, all variables included in the survey are significant. A 1% rise in economic growth (GDP) gives rise to a 2.71% rise in environmental pollution, i.e., CO2 emissions. This trend keeps climbing to a specific point in economic growth. Alias, in the initial stages of economic growth, economic growth gets larger environmental pollution. Nevertheless, this action then peaks at a turning point, and the status reverses in the later stages of economic growth. After this turning point, a 1% rise in economic growth (GDP2) begins to diminish environmental pollution, i.e., CO2 emissions, by 0.16%. Alias, as wealth rises, after a definite income level, more stature is given to the environment, and environmental pollution diminishes. Looking at the other variables in the survey, a 1% rise in energy use (ENG) gives rise to a 1.73% increment in environmental pollution, i.e., CO2 emissions, i.e., a 1% increase in trade (TRD) gives rise to a 2.08% diminish in CO2 emissions. A 1% rise in renewable energy consumption (REW) decrease CO2 emissions by 0.17%. A 1% rise in urban population density (URB), a control variable in the survey, boots environmental pollution, i.e., CO2 emissions, by 1.06%. Examining the variables in the survey, it is seen that the factor that most increments environmental pollution is the economic growth efforts of countries at low-income levels (GDP: 2.71%).

The survey verifies the existence of the EKC hypothesis. That is, environmental pollution first increases, then reaches a turning point, and then begins to diminishes. The calculation of this turning point is also vital. The turning point is calculated by taking the first derivative of Equation 2with respect to ln (GDP) and setting it equal to zero.

$$\frac{\partial \ln(CO2)}{\partial \ln(GDP)} = \beta 1 + 2\beta 2 \ln(GDP) = 0 \quad \rightarrow \quad \ln(GDP) = -\frac{\beta 1}{2\beta 2} \qquad (2)$$

Herein, a logarithmic value is existing. When the antilogarithm of this value is taken, a monetary turning point is acquired. This is indicating as follows:

$$Turning\ point = \exp\left(-\frac{\beta 1}{2\beta 2}\right) \qquad (3)$$

A Wald test was implemented to specify the turning point and whether it was statistically notable. Table 4 indicates the Wald test outcomes.

Table 4: Wald Test to Determine Turning Point For GDP.

log_CO2	**Coefficient**	**P>ll zll**
Turning_Point	3077.06	0.000

Table 4 demonstrates that the p-value specifies that the turning point is not a happenstance and is statistically remarkable at the 99% confidence level. Suitably, the turning point for the countries analysed is $3,077. This implies that environmental pollution rises until per capita national income attains $3,077, peaks at this income level, and then the influence of economic growth on environmental pollution changes from positive to negative. Alias, environmental pollution commences to diminishes. Analysing the current group of countries, it is evident that countries such as Türkiye, China, Brazil, and Mexico have undergone this turning point. To be more precise, countries with a per capita national income above $3,077 have moved pass the stage where economic growth pollutes the environment and has participated the stage where economic growth diminishes environmental pollution.

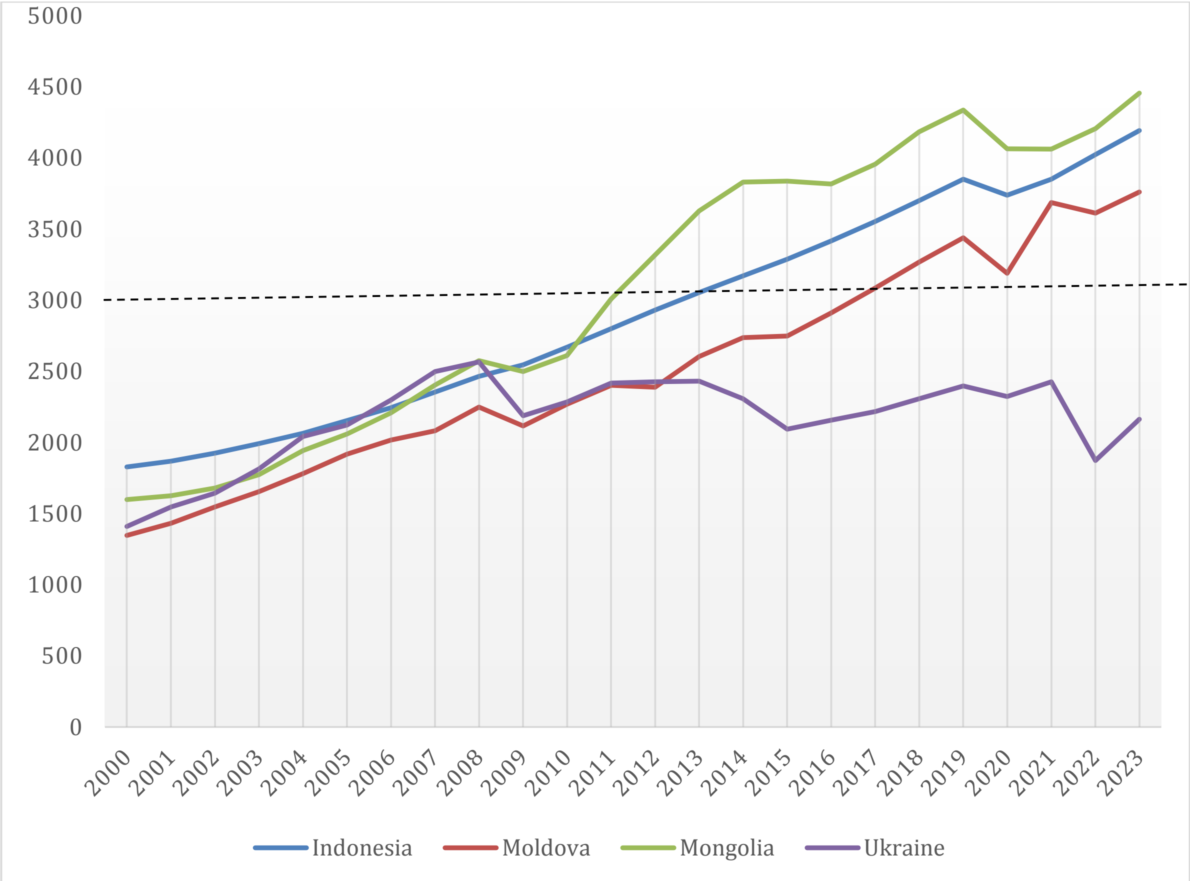

Figure 3: Countries Near the Turning Point Within the Sample Group.

Besides, Figure 3 demonstrates the countries with the minimum national income within the sample group and the turning points. In the period below the black dashed line in the figure, economic growth rises environmental pollution. Above the dashed line, economic growth diminishes environmental pollution. It is apparent that, Ukraine is till now in the stage where economic growth rises environmental pollution, while other countries have only a short time since moved past this stage. Besides, Albania, Azerbaijan, Belarus, Bosnia and Herzegovina, China, El Salvador, Gabon, Georgia, and Turkmenistan were in the stage where economic growth polluted the environment in the early 2000s, and only moved to the other stage in the following years.

5. CONCLUSION, DISCUSSION AND POLICY IMPLICATIONS

Figures This survey examines the validity of the Environmental Kuznets Curve (EKC) hypothesis for 37 developing countries categorized by the World Bank as upper-middle income. Besides, the influence of numerous macroeconomic determinants on environmental pollution is examined. The survey encompasses the period from 2000 to 2023, and the dataset was estimated utilizing the robust Parks-Kmenta FGLS method. The outcomes are elaborated on in the theoretical framework, and vital recommendations are submitted to policymakers. The empirical outcomes demonstrate a positive and statistically significant (2.71) GDP per capita coefficient, while the square of this variable (GDP^2) is significant but negative (-0.16). This outcome specifies that the EKC hypothesis is valid for the studied group of countries. Alias, there is a reverse U-shaped relation betwixt income (related to economic growth) and environmental pollution (CO_2 emissions). In economic literature, this status is described by the scale effect happening in the initial stages of economic growth, whilst production volume rises, it has a negative influence on the environment, meaning that environmental pollution intensifies as production rises (GDP elasticity 2.71%). Nevertheless, as the economy onward movement to more advanced stages, it develops and transitions to cleaner technologies. This structural alternation in the economy operates the technical effect, causing economic growth to diminish environmental pollution. The most vital outcome of the survey is the turning point level, whose significance was established by the Wald test. In the selected group of countries, the turning point was specified to be $3,077. A review of the literature demonstrates that the turning point is mostly calculated in the $10,000-$15,000 range for developed countries. The fact that the turning point for developing countries is below that of developed countries in this survey demonstrates that developing countries finish their industrial processes with cleaner technologies, i.e., technologies that pollute the environment less or not at all, compared to developed countries. This status is also correlative with the ′′leapfrogging theory′′ in the literature. As posited by this theory, developing countries, having entered industrialization and development processes later, are able to integrate recently developed and cleaner technologies into their systems without adopting the unproductive and environmentally polluting technologies that developed countries used during parallel periods in the past. This symbolizes a "leap forward," bypassing the old system. The survey deduces that selected developing countries, instead of repeating the polluting technologies used by developed countries in the past, immediately integrate new and clean technologies into their production processes, thus reaching this turning point at lower income levels. Countries like Türkiye, China, Mexico, and Brazil, which are leaders in terms of income level within the group, have already crossed this threshold, reaching a stage where economic growth cleans the environment. This REVEALS that economic growth policies in these countries no longer impair environmental sustainability; contrarily, they PROMOTE sustainability while EXECUTE economic growth.

Another crucial outcome of the survey is the demonstration that trade openness (TRD: -2.08) has a mitigating effect on environmental pollution (CO2 emissions). These outcomes deny the Pollution Haven Hypothesis found in the literature and demonstrates that the opposite hypothesis, the Pollution Hale Hypothesis, is current. As developing countries attend in global trade, there is a transference of productive and low-carbon clean technologies from developed countries to these countries. As countries open up to the outside world through global trade, not only have goods and services been exchanged betwixt them, but also "green know-how" has been carried. This outcome is also promoted by the surveys of Shahbaz et al. (2017) and Dogan & Seker (2016). Nevertheless, there are also researchers in the literature, such as Destek et al. (2018), who promote the Pollution Haven Hypothesis and make a decision that this status is not current for middle-income developing countries. The survey also made a decision that energy use (ENG: 1.73%), another variable, rises environmental pollution. This outcome is appropriate with presupposition, as inspecting the energy source combinations of the countries demonstrates that they are still mainly linked to fossil fuels. Although the outcomes regarding renewable energy (REW: -0.17) in the survey demonstrates that it helps diminish environmental pollution, the subdued coefficient demonstrates that the portion of renewable energy in the energy source combination is still negligible and accordingly it cannot push the "scale effect" of fossil fuels. The control variable of the survey, urbanization (URB: 1.06%), rises environmental pollution. In developing countries, urbanization is often speedy and unplanned. So, energy demands expand unplanned infrastructure pressures expand, and public transportation may become unsatisfactory. All these statuses give rise to an increase in environmental pollution.

Based on the outcomes, the following recommendations can be made to policymakers:

Figure 3 demonstrates the countries with the minimum income levels in the sample group. In these countries, incentives should be ensured to achieve production goals directly with clean energy sources without waiting for pollution to peak, while achieving economic growth goals.

Based on the understanding that free foreign trade declines pollution, countries should forego their protectionist policies and struggle to integrate more into the global trading system. Expressly, the import of environmentally friendly technologies such as solar panels, energy-efficient machinery and equipment, and wind turbines, which will rise renewable energy production, should be facilitated and taxes should be removed. Direct foreign investments should be stimulated to promote economic development goals and facilitate the transfer of green technologies. Endeavour should be made to maximize the advantage of the Halo effect of pollution.

It has been monitored that renewable energy investments need to be boosted and promoted. The transition from fossil fuel systems to renewable energy systems in industry should be subsidized. Both energy consumption should be boosted and CO2 emissions should be declined.

To alleviate the negative environmental influences of unplanned and chaotic urbanization, "Smart City" practices should be developed. This matter should focus on issues such as rail public transportation systems, energy-efficient building structures, and increasing the number of green spaces in cities.

Ultimately, the survey's outcomes reveal that the traditional view of "more growth means more pollution" is invalid. It displays that if economic growth goals are formed by sound energy and foreign trade policies, environmental pollution will not rise; rather, it will conduce to a cleaner environment.

REFERENCES

Allard, A., Takman, J., Uddin, G. S., & Ahmed, A. (2018). The N-shaped environmental Kuznets curve: an empirical evaluation using a panel quantile regression approach. *Environmental Science and Pollution Research*, 25(6), 5848-5861.

Al-Mulali, U., Saboori, B., & Ozturk, I. (2015). Investigating the environmental Kuznets curve hypothesis in Vietnam. *Energy Policy*, 76, 123–131.

Alola, A. A., Bekun, F. V., & Sarkodie, S. A. (2019). Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. *Science of the Total Environment*, 685, 702–709.

Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment? *The American Economic Review*, 91(4), 877–908.

Balsalobre-Lorente, D., Shahbaz, M., Roubaud, D., & Farhani, S. (2018). How economic growth, renewable electricity and natural resources contribute to CO2 emissions? *Energy Policy,* 113, 356–367.

Baltagi, B. H. (2005). *Econometric Analysis of Panel Data (3rd ed.).* John Wiley & Sons.

Birdsall, N., & Wheeler, D. (1993). Trade policy and industrial pollution in Latin America: where are the pollution havens?. *The Journal of Environment & Development*, 2(1), 137-149.

Copeland, B. R., & Taylor, M. S. (2004). Trade, growth, and the environment. *Journal of Economic Literature*, 42(1), 7-71.

Destek, M. A., Ulucak, R., & Dogan, E. (2018). Analyzing the environmental Kuznets curve for the EU countries: The role of ecological footprint. *Environmental Science and Pollution Research*, 25, 29387–29396.

Dogan, E., & Seker, F. (2016). Determinants of CO2 emissions in the European Union: The role of renewable and non-renewable energy. *Renewable Energy,* 94, 429–439.

Grossman, G. M., & Krueger, A. B. (1991). Environmental impacts of a North American free trade agreement. *National Bureau of Economic Research,* Working Paper, No. 3914.

IPCC. (2023). *Climate Change 2023: Synthesis Report.* Geneva, Switzerland. 70-77

Kmenta, J. (1986). *Elements of Econometrics (2nd ed.).* Macmillan.

Kuznets, S. (1955). Economic growth and income inequality. The American Economic Review, 45(1), 1– 28.

Martinez-Zarzoso, I., & Maruotti, A. (2011). The impact of urbanization on CO2 emissions: Evidence from developing countries. *Ecological Economics,* 70(7), 1344–1353.

Nathaniel, S., Anyanwu, O., & Shah, M. (2020). Renewable energy, urbanization, and ecological footprint in the Middle East and North Africa region. *Environmental science and pollution research*, 27(13), 14601-14613.

Oladunni, O. J., Olanrewaju, O. A., & Lee, C. K. (2024). The Environmental Kuznets Curve (EKC) Hypothesis on GHG emissions: analyses for transportation industry of South Africa. *Discover Sustainability*, 5(1), 302.

Panayotou, T. (1993). Empirical tests and policy analysis of environmental degradation at different stages of economic development. *ILO Working Papers*, 292778.

Parks, R. W. (1967). Efficient estimation of a system of regression equations when disturbances are both serially and contemporaneously correlated. *Journal of the American Statistical Association*, 62(318), 500–509.

Poumanyvong, P., & Kaneko, S. (2010). Does urbanization lead to less energy use and lower CO2 emissions? A cross-country analysis. *Ecological Economics*, 70(2), 434–444.

Sarkodie, S. A., & Strezov, V. (2019). A review on environmental Kuznets curve hypothesis using bibliometric and meta-analysis. *Science of the Total Environment*, 649, 128–145.

Shahbaz, M., & Sinha, A. (2019). Environmental Kuznets curve for CO2 emissions: A literature survey. *Journal of Economic Studies*, 46(1), 106–168.

Shahbaz, M., Nasreen, S., Ahmed, K., & Hammoudeh, S. (2017). Trade openness–carbon emissions nexus: The importance of turning points of trade openness for country panels. *Energy Economics*, 61, 221–232.

Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve. *World development*, 32(8), 1419-1439.

United Nations (2024). *The Sustainable Development Goals Report 2024*. 42

World Bank. (2026). *World Development Indicators*. https://databank.worldbank.org/source/world-

development-indicators
Yao, S., Zhang, S., & Zhang, X. (2019). Renewable energy, carbon emission and economic growth: A revised environmental Kuznets Curve perspective. *Journal of cleaner production*, 235, 1338-1352.
Zarsky, L. (1999). Havens, halos and spaghetti: Untangling the evidence about foreign direct investment and the environment. *OECD Conference on Foreign Direct Investment and the Environment*, The Hague. 54-55