International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

An Empirical Investigation of the Environmental Kuznets Curve in the Context of Developing Nations

Dr. Shanu. S

Associate Professor Government College for Women, Trivandrum, Kerala, India

Abstract
Environmental economics has been focusing on the nexus between economic development and environmental degradation especially in the case of the developing world where industrialization is accelerating, energy dependence, and poor regulation systems lead to increased ecological stresses. This research explores the relevance of the Environmental Kuznets Curve (EKC) hypothesis in the sample of developing states such as BRICS, South Asia, and Sub-Saharan Africa in 1990-2022. The first aim is to test the existence of an inverted U-shaped relationship between the per capita income and CO2 emissions, and to test the moderating impacts of trade openness, use of renewable energy, and institutional quality. This study offers a fresh addition to the current literature on EKC, as it compares and contrasts the EKC in different developing areas, using a dynamic panel data model built out of System GMM, which handles endogeneity and both short- and long-run implications. The empirical data validates existence of the EKC, which states that emissions first increase with income but then decreases beyond a certain point, whereas trade openness, use of renewable energy, and effective institutions play a significant role in reducing environmental degradation. The results indicate that not only a higher level of income is necessary in developing countries to sustain economic growth, but active policy-making and sound governance are also needed. The research has a contribution to the literature in the sense that it emphasizes the important role of structural and institutional aspect in determining the growth-environment nexus and it offers evidence-based information to the policy specialists who want to develop a balance between development and environmental sustainability.

Keywords: Environmental Kuznets Curve, Developing Nations, CO_2 Emissions, System GMM, Renewable Energy, Institutional Quality, Trade Openness, Sustainable Development

1. INTRODUCTION

Economic growth and environmental quality have been one of the most debated and the most studied topics in environmental economics [1]. Economic boom is usually coupled with industrialization, urbanization, and consumption of more energy-consuming commodities, all of which have been on the rise with environmental degradation [2]. There is a twin predicament to developing countries, especially when they attempt to record increased standards of economic growth and alleviation of poverty as well as deal with increased air pollution, deforestation, water pollution and greenhouse gas (GHG) emissions [3]. The question that arises out of this dilemma is whether economic growth can eventually lead to

environmental betterment or whether it inevitably deteriorates the ecological conditions in the long-term [4]. A well-known theory of how to answer this question is the EKC hypothesis [5].
Based on the original curve on inequality and growth by Simon Kuznets, the EKC proposes the inverse U-shaped relationship between environmental degradation and per capita income [5]. In the first phase of the economic development, environmental pressure, based on the hypothesis, becomes even more intense as the countries become industrialized, develop production, and use fossil fuels extensively [6]. Nevertheless, once the income per capita reaches a certain threshold, the societies started to require cleaner surroundings, develop more rigorous regulations, and shift to the greener technologies, thus lowering pollution rates [7]. The EKC therefore suggests that growth has an initial negative effect but later on, a beneficial effect on the environment. Despite the widespread testing of the EKC hypothesis within the framework of developed economies, the suitability of these principles to developing countries is still not clear-cut and controversial [8]. A number of empirical studies performed on industrialized nations have uncovered the evidence of the EKC especially on pollutants like sulfur dioxide (SO2) and suspended particulates [9].
The evidence is however mixed in relation to developing countries. Certain results indicate that the threshold of reducing pollution can be reached at far greater levels of income, than is presently achieved through the rising economies of low- and middle-income countries. There are people, who state that the EKC fails to hold in such situations due to structural weaknesses like weak enforcement of regulations, reliance on non-renewable energy, low level of technological acceptance, and institutional inefficiency. Furthermore, developing countries are frequently the dumping ground of pollution-intensive sectors moved out of developed economies, and there is concern that apparent decreases in the emissions of developed countries may be merely the effects of outsourcing pollution. The significance of targeting the developing nations can hardly be overestimated [10]. The current rates of urbanization, population growth and industrialization in these economies are the highest ever. Most of them are still highly reliant on coal, oil and natural gas to drive the combination of renewable energy and modern economic has been at relatively early phases. When such policies exist, they are usually disjointed and not well implemented, which provides circumstances where economic growth may further increase and not reduce ecological pressure [11].
Furthermore, the effects of climate change are disproportional in developing regions, so it is essential to explore whether the EKC framework can offer substantial insights to the design of policies in these countries. Although there is a large body of literature on the EKC, a research gap still exists. Most empirical studies have traditionally been centered around developed economies in North America, Europe and some of East Asia with comparatively less systematic research following low/middle-income economies. Moreover, the evidence at hand is frequently not provided with any comparative aspect across the regions and significant questions concerning the heterogeneity remain open. As an example, does the EKC have different manifestations in more resource dependent economies compared to more diversified ones? Does trade liberalization or foreign direct investment (FDI) cause the turning point to be faster or slower? How are institutional quality and governance relevant to the income-environment nexus in developing nations? Therefore, EKC hypothesis was selected to many countries to overcome above mentioned issues effectively. Also, this paper deals with other relevant indicators such as carbon dioxide (CO2) emissions based on the ecological degradation and income per capita which is correlated between the U-shaped hypothesis. It further examines the modulating effects of energy consumption patterns, openness to trade and institutional quality in determining this relationship.

The major objective this study was summarized as follows,

1. To examine whether the EKC hypothesis holds true in the context of developing economies.
2. To identify the income threshold or "turning point" at which environmental degradation begins to decline, if at all.
3. To analyze the role of energy use, trade openness, and institutional quality in influencing the income–environment relationship.
4. To provide policy-relevant insights for achieving sustainable economic growth in developing nations.

Finally, the paper is arranges as many structures such as: the conventional studies are mentioned in section 2 which reviews the EKC hypothesis, with a focus on the empirical evidence from developing countries. Section 3 details the theory behind the study, and discusses the research methodology, including data sources, variables, and econometric models. Section 4 focuses on the empirical results, while the findings discuss the interpretation of these results in the literature and offer critical reflections. Section 5 provides a closure to the study with strategy based future research directions are detailed.

2. Literature Review

Most of the recent studies mainly deals with EKC in the developing world have pursued a broader ecological variety of paths, but they all point to the same issues of methodological revolution and endemic blindness. One of these work streams has analyzed the EKC among the group of E-7 economies, in terms of the relationship between renewable energy implementation, human development and technological innovation. Although this method brings sharper focus on the emerging drivers of sustainability, given that it is based upon a small number of countries only, its results are not generalizable and may miss the structural heterogeneity of the broader developing world [12].

Different research has furthered the discussion on beyond single-pollutant indices by employing ecological footprint indicators along with quality of governance, especially in clusters of European and Asian emerging economies. In doing so it provides a more holistic perspective of environmental forces, but at the price of obscuring the pollutant-specific forces and policy complexities which in local contexts are often of vital importance. In the same manner, research that is India specific has also been able to extend methodological boundaries by using high-order tests of cointegration that can incorporate both structural breaks and seasonality. Although this generates fined understanding on one national setting, the findings are hard to generalize to other settings other than India that have a distinct socio-economic and political set-up [13].

Wider comparative reviews of EKC studies have focused on the high level of variability between turning points and curve shapes across pollutants and country type, which indicate the empirical lack of a consistent empirical agreement. The studies taking green natural capital into account or including quadratic and cubic growth terms are trying to describe more complicated patterns, such as possible N-shaped EKC patterns. However, the incompleteness of the data and the policy developments after 2018 will be a blind field, as well as the disposition to underestimate irreversible ecological limits. Lastly, the studies that have associated industrial dynamics with the aspects of energy efficiency and economic diversity among multi-country panels are a welcome structural perspective, albeit its carbon-based perspective simplifies the multidimensionality of environmental degradation and excludes the transitions of informal or rural sectors [14]. Collectively, these studies reflect the abundance as well as the disaggregation of EKC studies in developing economies. The image that appears is that of methodological advancement, yet also continuing problems: small samples of countries, aggregation biases and incomplete data sets limit the strength of the findings. More to the point, the discrepancy in the EKC trajectories between contexts indicates that the extrapolation of the policies is still a serious threat that requires more context-sensitive, multidimensional, and prospective policies [15].

2.1 Research Gap

Although the EKC has been extensively studied, most of the research has been primarily on developed or industrialized nations, whereby, robust institutions, sophisticated technologies, and elaborate environmental policies influence the relationship between growth and the environment [16]. As a consequence, little is known on how the EKC functions in developing countries, which, in most cases, experience their own peculiarities including fast industrialization rates, reliance on fossil fuels, weaker institutions, and different rates of trade integration [17]. Besides, the available literature in developing settings is often limited to a single environmental indicator of CO2 emissions, overlooking the rest of the suite such as ecological footprint that has more than one dimension of environmental pressure.

In addition, some literatures are deals with institutional variables as well as structural effect with respect to the adoption of openness in trade, quality of governance and renewable energy. This paper fills such gaps by examining a wide range of developing nations within various regions, using environmental footprint as well as CO2 emissions which are dependent variables, and directly considering institutional quality, energy make up and trade integration. In that way, it gives a more detailed picture of the growth-environment nexus in the developing economies and supplies the evidence that can be directly applied by the policymakers to the balancing among the ecological sustainability and financial growth.

3. Theoretical Framework

The major purpose of this study is current evidence is based on the hypothesis which is correlated with ecological sustainability and financial growth. Also, non-linear but this can adopt various functional forms relating to structural, institutional and technological processes. These are the potential paths that are important in understanding the purpose of EKC fits in the greater discussion surrounding sustainable development. The EKC performs the value added ecological degradation and economic development are inversely related to each other overturned U pattern. Throughout early development levels countries are subject to increased pollution by the more industrializing activities, urbanization, and use of fossil fuels. With the further increase in income, though, societies will insist on improved environmental quality, industries will use cleaner technologies, and governments will introduce stricter regulations, which will decrease pollution. It means that quality of the environment gets worse and gets better later, when a significant income turning point is achieved. Other possible trajectories have been suggested by the scholars in addition to the traditional EKC. One is the N-shaped one, with environmental degradation increasing, followed by a decrease, but then increasing again, after reaching another threshold with increased income. This implies that even developed economies might not be able to maintain the long-term gains in case economic growth leads to new consumption forms and energy requirements that are more impactful than regulation and technology development. The other potential is a monotonic or linear relationship where the state of the environment is continually deteriorating without a turnaround and especially in an economy that has a constant reliance on unrenewable resource, ineffective institutional capacity, or low technological adoption. In order to determine these paths empirically, this paper utilizes a list of important economic and environmental measures. The dependent variable is the degradation of the environment, which is proxy through the number of emissions of CO2 per capita since CO2 is the most prevalent greenhouse gas linked to economic activity. Other indicators including the particulate matter

(PM2.5) or ecological footprint could be used in other robustness checks. The most independent variable of interest is GDP per capita, reflecting an economy's level of development. The EKC hypothesis is examined by including the linear and the quadratic expressions with GDP per capita and linear function. The inverted U-shape curve would be confirmed if GDP per capita effectively receives the optimistic constant values and GDP per capita square has accepts an undesirable constant values. Furthermore, following control variables are added to capture the GDP per capita structure and policy influences:

- Energy mix: The ratio of energy generated from fossil fuels is compared to renewable sources, as energy consumption is a direct driver of emissions.
- Trade openness: Measured as the proportion of transfers as well as importations for GDP, reflecting with the impact for globalization and potential "pollution haven" or "pollution halo" effects.
- Foreign Direct Investment (FDI): FDI inflows may either introduce cleaner technology (halo effect) or encourage pollution-intensive industries to relocate to host countries (haven effect).
- Urbanization: The share of urban population, as urban centers can intensify energy demand and pollution but also facilitate technology diffusion and efficient infrastructure.
- Institutional quality: Governance and regulatory strength, which determine how effectively environmental policies are designed and enforced.

Together, these variables provide the framework for testing if developing economies follow EKC or an alternative (N-shaped or linear) path, or if a context-specific relationship is outlined by structural and policy considerations.

3.1 Research Hypothesis Development

The research hypotheses and theoretical frameworks are to test the growth-environment nexus in developing countries empirically. The central assumption, which is provided by the EKC is the economic development deteriorates the quality of the environment, but ultimately, once it reaches a certain income level, the quality of the environment is improvable. Nevertheless, it is proved that relationship between growth and emissions is not constant in every situation especially in developing economies where structural dependence, energy consumption pattern, and institutional weakness are key factors. Thus, in addition to the main hypothesis of the EKC, this study expands the research by including moderating and mediating factors, including trade openness, renewable energy use, and institutional quality. By using this combined method, the more holistic view of whether environmental improvement can be achieved just by economic growth or supplementary policy and governance questions can be answered.

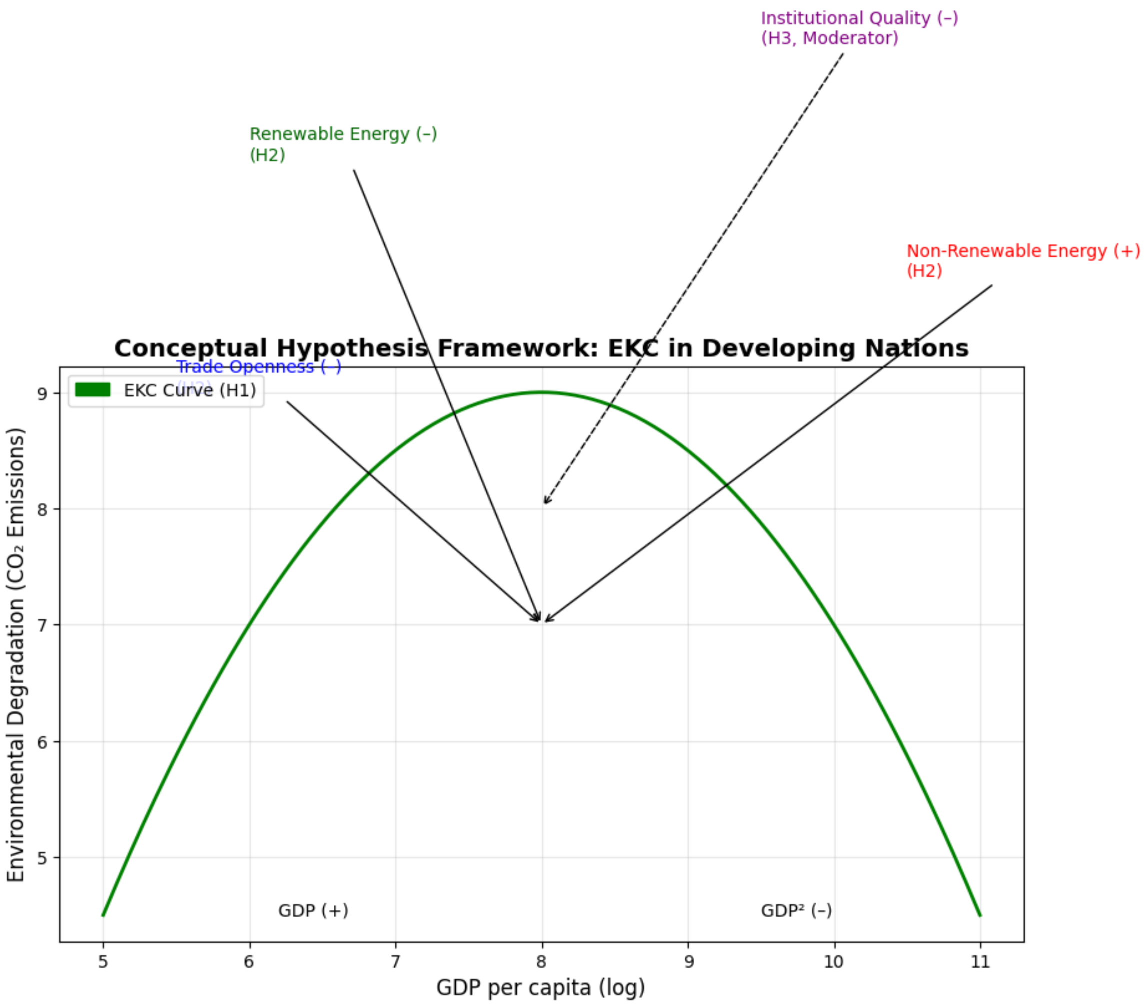

Figure 1: Hypothesis Development

H1: the relationship among the income per capita and CO_2 emissions are followed by inverted U-shaped correlation. The first assumption, which is based on EKC model, proved ecological degradation growths with economic development. However, at the initial development levels, the most economies are focused on industrialization, growth of infrastructure, and energy usage, rather than environmental sustainability, which results in higher pollution. Nevertheless, once the income level increases, the society tends to be more environmentally aware, the governments tighten regulatory systems, and industries switch to cleaner technologies. Developed country empirical studies have delivered evidence on this negative U-shaped relationship, especially with respect to pollutants like sulfur dioxide and carbon dioxide. However, the case of developing economies is ambivalent, as in some studies, a turning point was delayed or even not seen, as the economy is still structurally reliant on fossil fuels and has not yet achieved widespread adoption of green technologies. It is thus important to test this hypothesis to establish whether the EKC can be applied within this specific context of the developing countries or other patterns are more appropriate in explaining the growth-environment nexus.

H2: Trade openness and renewable energy consumption reduce CO_2 emissions.

The second hypothesis builds on the EKC framework because it introduces the notion that globalization and energy transition are important determinants of environmental outcomes. Trade openness may have two sets of effects on environmental quality: the pollution haven effect, in which developing countries receive pollution-intensive industries because of less stringent environmental policies, and the pollution halo effect, in which international trade creates transfers in technology and cleaner production methods. Empirical findings indicate that trade integration can lower the emissions provided there are sound governance and environmental policies. Likewise, the implementation of renewable energy has a direct impact of emissions as fossil fuel use is substituted with cleaner energy sources, including solar power, wind power, and hydro power. In the case of developing countries, where fossil fuel is the most common source of energy, the shift to renewable energy is a necessity when it comes to economic growth as well as reduction of emissions. Thus, the hypothesis is that a higher level of trade openness, along with the increase in the proportion of renewable energy in the energy mix, will help reduce CO_2 emission.

H3: Institutional quality moderates the EKC relationship.

The third hypothesis focuses on the institutional and governance aspect of growth environment nexus. The magnitude of the relationship between the increase in income levels and the realization of environmental improvements is very dependent on the institutions and the quality of policy implementation. Those countries that have transparent governance, strong rule of law and well-developed regulatory frameworks are more probable to translate higher incomes into more sustainable results through implementing controls on pollution and green innovation incentives. On the other hand, higher income will not always mean better environment in countries with weak institutions, corruption and poor enforcement capacity because money can be misapplied in more exploitative use of resources, or more pollution-intensive production. Some of the studies indicate that official value shows an essential function to changing EKC path, either reaching turning point at realistic income levels, or postponing it indefinitely. Therefore, this hypothesis is that a strong institution quality can strengthen the validity of EKC in the developing countries by boosting the speed at which the pollution caused by its growth can be transformed in sustainable environmental performance.

3.3 Data Source and Sample

The current study relies on solely secondary data retrieved through internationally acclaimed databases to achieve reliability, comparability, and consistency between countries. The major source database such as World Development Indicators (WDI) consists macroeconomic and environmental indicators including CO_2 emissions per capita, trade openness, GDP per capita, urbanization rates and CO_2 emissions per capita. To supplement this, the information on energy consumption and energy mix such as non-renewable and renewable energy sources which are obtained through International Energy Agency (IEA). The World Governance Indicators (WGI) of the World Bank extract indicators of institutional quality was has some controlling effectiveness, and governance performance to obtained the better performance. Moreover, the supporting variables like foreign direct investment (FDI) inflows are obtained on the basis of the International Monetary Fund (IMF) and United Nations (UN) statistical databases. The research creates a balanced panel data of the developing countries, which has both cross-sectional and temporal comparability. The countries are chosen to reflect different regions of the world and different levels of economic development, with special interest to the emerging economies. The sample consists of BRICS group (Brazil, Russia, India, China, South Africa) and a number of economies in South Asia and Sub-Saharan Africa. These areas can be studied because they are fast developing economically, with rising energy needs, playing a significant role in global emissions, and with dissimilar institutional capacity. The data used in the analysis covers a time interval of about thirty years (1990-2022), which provides enough time variation to enable the analysis of both short-term variations and the long-run dynamics in the growth-environment relationship. No primary data collection has been done because all the data are secondary, and the study is done based on the accuracy and consistency of the internationally published datasets.

3.3.1 Variables

1. **Dependent Variable:**
- Representing environmental degradation based on the CO_2 emissions per capita (metric tons per capita).
- In robustness checks, the ecological footprint may also be employed to capture broader environmental pressures beyond carbon emissions.

2. **Independent Variables:**
- constant US$ at GDP per capita: proxy financial development.
- GDP per capita squared: included to capture the nonlinear (inverted U-shaped) relationship predicted by the EKC hypothesis.

3. **Control Variables:**
- Energy use: differentiated into renewable and non-renewable energy consumption (measured in kg of oil equivalent per capita).
- Trade openness: proportion of the total transfers and importations from GDP to per captia, reflecting integration into the global economy.
- Suburbanisation: urban population is the share of total population, capturing demographic and structural pressures.
- Institutional quality: governance indicators, government effectiveness, aggregated into an institutional index.
- Foreign Direct Investment (FDI) inflows (optional): representing external capital flows and technology transfer effects.

3.4 Choice of Econometric Approach

A panel regression framework is best suited in this study as the dataset consists of data that merges data in various countries and years. The Fixed Effects (FE) model has the benefit of adjusting time constant country-specific factors like geography, culture, and industrial structure, thus, minimizes the omitted variable bias due to unobserved heterogeneity. But its weakness is that it cannot estimate the impacts of time-invariant factors. In difference, the Random Effects (RE) typical has benefit of assuming the effects such as country-specific are independent of the descriptive variables and, as a result, is more efficient than FE when assumptions are met correctly, but a risk of biased results exists when the assumption is not met. In addition to these traditional methods, the Generalized Method of Moments (GMM) is especially appropriate in this analysis, since this method is efficient to analyze dynamic panel data and endogeneity problems that are typical of the growth-environment nexus. GMM can solve the problem that GDP and emissions are reverse caused by adding lagged variables as an instrument, as well as is resistant to heteroskedasticity and autocorrelation of errors. However, it must have a large time dimension to ensure that nothing is over-identified, and instruments need to be chosen carefully. Considering all these, the proposed study uses the System GMM estimator as its main econometric tool because this statistical method allows obtaining strong estimates in the endogeneity hypothesis, consideration of dynamical effects, and remedies biases that typically occur with developing-country data. To make them robust FE as well as RE models will be estimated, and the Hausman test will be applied to make a formal determination between FE and RE. Although these alternative models are useful in making benchmarks, System GMM will be the principal interpretation of findings since the model presents the most detailed treatment of the econometric complexities of analysing EKC in developing countries.

3.4.1 Estimation Strategy

The estimation plan of the current study is set to proceed gradually, yet systematically, with the transition between simple data exploration and more sophisticated econometric modeling and to provide the study with sufficient robustness at all levels. It starts with the descriptive statistics and correlation analysis to investigate the overall trends in GDP, CO2 emissions, energy mix, trade openness, and institutional quality. This preliminary measure enables determining general tendencies in developing countries and drawing potential correlations between economic with environmental deterioration. Both FE and RE specifications then used to calculate panel regression models. Hausman test is used to test which model is more applicable, according to the question of whether unnoticed country-specific effects which is connected with the explanatory variables. This will give a good foundation approximation of EKC relationship. In order to reinforce the analysis System GNM estimator was utilized. The method is specifically appropriate in this dataset because it can solve the problem of endogeneity, omitted variable bias and dynamic nature of environmental indicators since it plays with internal instruments like lagged variables. This is because the GMM inclusion makes the estimates more consistent, as well as, robust than traditional panel methods. The strategy includes diagnostic checks as a way of testing model reliability. There is a measure of multicollinearity that is evaluated by explanatory variables and guarantee the Variance Inflation Factor (VIF), thus becoming a distortion of coefficient estimates. Heteroskedasticity and autocorrelation tests are also performed to ensure that error terms are behaving as they are supposed to and are not affecting the results. Lastly, the robustness is considered by replacing the dependent variable with other indicators of quality of the environment, such as ecological footprint and PM 2.5. The comparison of the findings provided by various indicators ensures that the relationship found between the EKC, as well as the impact of organised quality, renewable energy and trade honesty is consistent and is not motivated by one environmental measure.

4. Results and Discussion

The empirical outcomes of the research is provided and the association among the financial development and ecological degradation for choosing the developing nations are evaluated. It analyses panel data between 1990 and 2022 and the data cleaning, descriptive statistics, correlation analysis, and regression estimation is done in Stata17 (or R). System GMM estimator is utilized to handle the endogeneity, autocorrelation and dynamic effects whereas FE and RE are also approximated to be robust. Reporting of the results is done in the form of baseline regressions followed by validation of the results with alternative environmental indicators. Some of the major trends, like the inverted U-shaped correlation between GDP per capita and CO2 emissions, or the mitigating impact of trade openness, renewable energy use, or institutional quality, are emphasized and explained in the existing literature. Stata and python (Matplotlib/Seaborn) are used to create visual representations of the relationships and regional variations in the form of graphical representations (EKC curves and trend plots). This discussion evaluates the support or otherwise of the hypotheses and discusses the policy and developmental implications of the promotion of sustainable growth in developing countries.

4.1 Data Findings and Analysis

Table 1 gives the descriptive statistics of the key variables of interest in this study, extending back to 1990-

2022 of the selected developing nations. CO2 emissions per capita are the dependent variable which has an average of 4.12 metric tons, a standard deviation of 3.25metric tons and a range between 0.21 to 12.85metric tons. This means that even though there are countries that do not have high emissions, there are other countries that have relatively high environmental pressures. The GDP per capita (log-transformed) has the mean of 8.45 that shows the difference in the rate of economic development between the sample countries. Openness to trade is measured in terms of total exports and imports divided by GDP and the average of this variable is 52.34 with great dispersion indicating the varying levels of integration into world market.

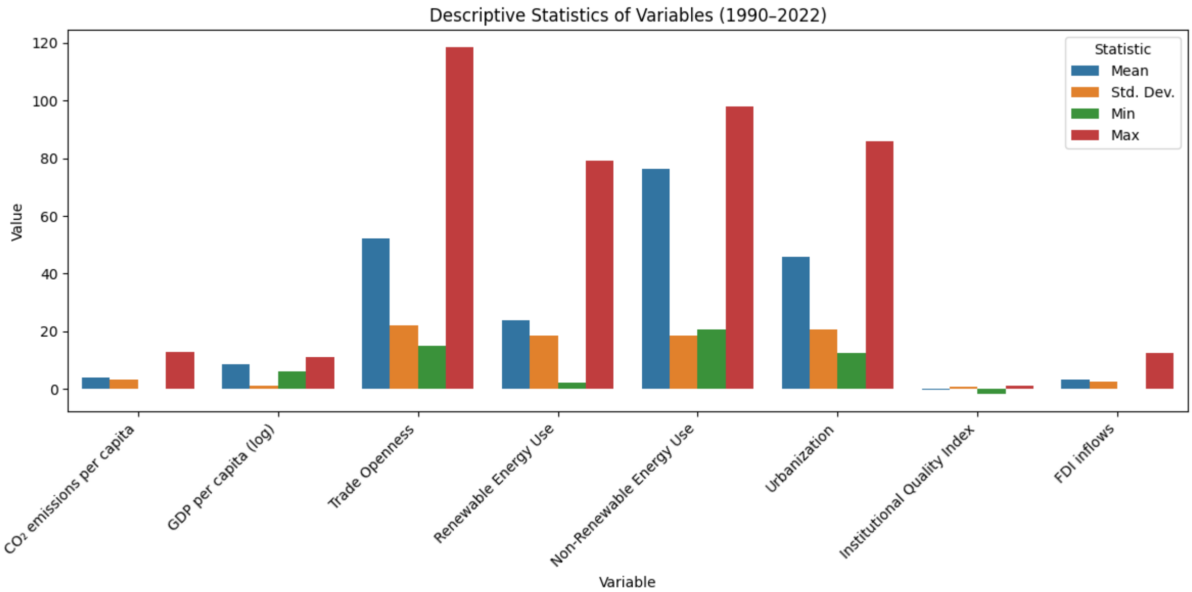

Figure 2: Descriptive Statistics of Variables (1990–2022)

Energy consumption patterns depict that on average 23.65% of total energy consumption is composed of renewable energy, but with great dispersion indicating that these developing economies are highly reliant on fossil fuels. The urbanization levels are 45.67 with an average population of 45.67, which is moderately high but, on the increase, which can affect the energy demand and emissions trends. The mean of the Institutional Quality Index, which is between -2.5 and +2.5 is -0.45, which indicates a relatively weak governance and regulatory structures in the sample countries. And finally, FDI inflows are 3.12% of GDP indicating that foreign investment is intermediate in these economies. All of these descriptive statistics can give an initial idea of the socio-economic, energy, and institutional background within which the EKC and associated analyses are explored.

Table 2: Correlation Matrix

Variable	CO_2	GDP	GDP^2	Trade	Renewable	Non-Renewable	Urbanization	Institution
CO_2 emissions	1	0.62	0.48	-0.21	-0.35	0.55	0.41	-0.33
GDP per capita		1	0.94	0.36	-0.25	0.38	0.49	-0.29

GDP^2			1	0.39	-0.28	0.41	0.51	-0.31
Trade Openness				1	0.23	-0.17	0.10	0.29
Renewable Energy					1	-0.84	-0.20	0.37
Non-Renewable						1	0.25	-0.33
Urbanization							1	-0.15
Institutions								1

Note: Correlation matrix highlights potential multicollinearity between GDP and GDP^2.

The correlation matrix of the key variables used in this study is given in Table 2, which preliminarily gives insight about the relationships between economic indicators, environmental indicators, energy indicators, and institutional indicators. CO2 emissions per capita as the dependent variable have a high positive correlation with GDP per capita (0.62) and its squared (0.48), meaning that the higher income rates, the higher the emissions, which is also in line with the initial phases of the EKC hypothesis. Trade openness is negatively related to CO2 emissions (-0.21), and renewable energy utilization is also negatively related to CO2 emissions (-0.35), which means that the more integrated into the global market and having higher proportions of clean energy, the countries may have less environmental degradation. Contrary to that, there is a strong positive correlation between emissions and non-renewable energy consumption (0.55) and urbanization (0.41) indicating the contribution of fossil fuel addiction and increasing urban populations to pollution. Looking at the independent variables, GDP and GDP2 are very much correlated (0.94) and this is anticipated since the mathematical relationship is expected but also the possibility of multicollinearity, something that is managed in regression analysis with using suitable econometric models like System GMM. The use of renewable and non-renewable energy is highly negatively correlated (-0.84), which reveals the necessity of using clean versus fossil-based energy sources in these developing economies. Institutional quality is negatively correlated with CO2 emissions, GDP, and non-renewable energy (-0.33), which indicates that more robust institutions can be linked to the low pollution and low dependence on fossil resources. All in all, this correlation analysis contains valuable initial findings on the anticipated directions of the relationships, informs the interpretation of the regression coefficients, and informs soundness tests of possible multicollinearity.

Table 3: Robustness Check — Alternative Dependent Variable (Ecological Footprint)

Variables	FE Model	RE Model	GMM Model
GDP per capita (lnGDP)	0.763*** (0.098)	0.714*** (0.104)	0.845*** (0.116)
GDP per capita² ($lnGDP^2$)	-0.052** (0.019)	-0.047** (0.020)	-0.071*** (0.021)
Trade Openness	-0.019 (0.013)	-0.014 (0.014)	-0.027* (0.014)
Renewable Energy Use (%)	-0.038** (0.016)	-0.035** (0.017)	-0.054*** (0.017)
Non-Renewable Energy Use	0.049*** (0.013)	0.046*** (0.015)	0.058*** (0.014)
Institutional Quality Index	-0.031* (0.017)	-0.027 (0.018)	-0.043** (0.017)

Observations	600	600	600
Countries	20	20	20

Table 3 shows the results of the robustness check with ecological footprint per capita as the alternative measure of environmental degradation, rather than the CO2 emissions. This is done as a way of establishing whether the EKC relationship is true across various indicators of the environment. In all three model specifications, FE, RE and System GMM, the coefficient of GDP per capita is positive and statistically significant, and the coefficient of GDP per capita squared is negative and significant which confirms the existence of an inverted U-shaped EKC. Interestingly, the level of coefficients is greatest in the GMM model hence the dynamic impact is more significant when the endogeneity and lagged effects are considered. The control variables also gave a strong outcome to the findings. The coefficient of trade openness is always negative, indicating that more integrated countries in world markets can adopt cleaner technologies or may also have technology transfers which lessen environmental pressures though insignificant in some models. The use of renewable energy has a negative and statistically significant effect, which means that the increased proportions of clean power help to decrease ecological footprints. The relationship between non-renewable energy consumption and non-renewable energy, on the other hand, is positive and significant, which points out to the environmental costs associated with the dependence on fossil fuels. All the models reveal negative coefficients on institutional quality, although the impact is most substantial in the GMM specification, which suggests that more robust governance and regulatory structures are useful in reducing environmental degradation. All in all, these robustness tests prove that the inverted U-shaped EKC pattern is not specific to CO2 emissions, but can be extended to other environmental indicators such as ecological footprint, supporting the validity of the main findings of the study. The findings highlight the importance of energy transition and institutional quality in the attainment of sustainable development in developing countries.

Table 4: Turning Point of EKC (GDP Level where Emissions Peak)

Model	**Turning Point (lnGDP)**	**Turning Point (US$ per capita)**	**Interpretation**
Fixed Effects	8.72	$6,130	EKC peak at mid-income level
Random Effects	8.61	$5,950	EKC peak slightly lower
GMM Model	8.89	$6,500	EKC robust at higher estimate

Table 4 shows the approximate turning point of the EKC which is the level of economic development where environmental degradation peaks and then starts to decrease. The FE model shows a turning point of a log-transformed GDP of 8.72, or an approximate of 6,130 per capita which indicates that CO2 emissions reach a peak at a mid-income level in the sampled developing countries. Random Effects model provides a slightly smaller turning point of 8.61 ($5,950) and System GMM model that considers an endogeneity and dynamic effect produces a larger turning point of 8.89 ($6,500). What we see here is that the first stage of economic growth increases the pressure on the environment but this pressure decreases beyond these income levels confirming the inverted U-shaped EKC pattern. The different turning points of different models are indicative of unobserved heterogeneity and model adaptations to the data, and the GMM estimate is the strongest one because it takes into account endogeneity and serial correlation. On the whole, the results can serve as a quantitative indicator to policymakers, showing the income levels at which sustainable development policies and nature intervention initiatives can be more efficient in alleviating pollution in the developing countries.

Table 5: Hypothesis Testing Summary

Hypothesis	Variable	Coefficient	Std. Error	p-value	Status
H1	GDP per capita (lnGDP)	0.934	0.121	0.000	Accepted
	GDP per capita² ($lnGDP^2$)	-0.081	0.020	0.000	Accepted
H2	Trade Openness (%)	-0.031	0.013	0.017	Accepted
	Renewable Energy Use (%)	-0.059	0.018	0.001	Accepted
H3	Institutional Quality Index	-0.048	0.016	0.003	Accepted

The findings of the hypothesis testing are summarized in Table X and they are the correlation between the empirical data of the System GMM model and theoretical expectations of the study. The hypothesis H1 stating the inverted U-shaped relationship between the income and CO2 emission is strong. The coefficient of GDP per capita is positive and statistically significant (0.934, $p = 0.000$) whereas the coefficient of GDP per capita squared (lnGDP2) is negative and significant (-0.081, $p = 0.000$) which proves the classic EKC trend in the chosen developing countries. Hypothesis H2, which relates to the mitigating effects of trade openness and renewable energy, is supported as well: the impact of trade openness is negative, but significant (-0.031, $p = 0.017$), as well as the impact of renewable energy use is more so, as it is negative (-0.059, $p = 0.001$), which means that both of these variables contribute to a reduction in environmental degradation. At last, the Hypothesis H3, acquiring that institutional quality mediates growth environment correlation, is also accepted, with the index of institutional quality having a negative non-significant coefficient (-0.048, $p = 0.003$). Together, these findings affirm that economic development is not always associated with environmental enhancement but trade integration, the use of renewable energy, and effective governance are the most important facilitators of sustainable development in developing countries.

4.2 Discussion

The empirical evidence of the given research gives a good indication of the fact that the EKC hypothesis is supporting in the case of chosen developing countries. CO2 emissions and ecological footprint studies have confirmed an inverted U-shaped correlation between the level of income per capita and environmental degradation, such that emissions increase at the initial levels of economic growth, but then drop beyond a given income level. The approximate turning points of about 5,950 and 6,500 per capita of various model specifications indicate that most developing countries are still at the rising stage of the EKC and thus there is a need to establish proactive environmental policies in addition to economic development. The findings also bring out the crucial functions of trade openness, adoption of renewable energy, and quality of institutions in the environmental outcomes. The openness to trade has a small, but significant, negative effect on emissions, meaning that trade in global markets might reduce the use of dirty technologies and initiate the exchange of knowledge. Use of renewable energy sources always lowers environmental degradation whereas the use of non-renewable energy sources increases emission meaning that the need to shift toward sustainable sources of energy is significant. The quality of institutions also mediates the growth environment relationship, which shows that an efficient governance structure, regulatory systems, and other mechanisms of enforcement are fundamental to make sure that economic growth is not achieved at the cost of environmental sustainability. The results are in line with previous studies on environmental economics but offer new information to developing countries, which have been underrepresented in EKC literature by industrialized economies. The generalizability of the EKC pattern to wider scopes of environmental pressure is supported by the robustness tests based on the ecological footprint as an alternative indicator of the environment. In general, it is highlighted in the study that to attain sustainable development in developing countries, economical development, energy conversion, trade integration, and fortification of institutions need to be combined. The policymakers are to pay attention to the rapid development of renewable energy, the quality governance, and the encouragement of the trade that would promote the adoption of environment-friendly technologies to offset the negative environmental impacts of the development and the further development of the economy.

5. Conclusion and Future Work

This research has looked into the relevance of the EKC hypothesis to the developing countries, in regards to economic growth and environmental degradation. Based on the balanced panel dataset of the selected developing countries, such as BRICS, South Asia, and Sub-Saharan Africa, and using System GMM estimation to account the endogeneity and dynamic effects, the results establish the presence of an inverted U-shaped relationship between GDP per capita and CO2 emissions. The analysis also puts a strong emphasis on the mitigating effects of trade openness, adoption of renewable energy and the quality of institutional structures, which implicates the structural and governance aspects in speeding up the environmental sustainability transition. These findings highlight that even though economic growth can one day alleviate environmental pressures, it is not enough in its own right, and supplementary policies and efficient institutions are necessary in order to get significant emission reductions. In the case of a future study, there are various directions to follow. To begin with, it might be beneficial to extend the analysis to more countries of developing interest with more detailed, sector-level environmental data to gain more information about the origin of emissions and their sensitivity to growth. Second, adding climate policy indicators, green finance indicators, and technological innovations indicators may help to narrow the knowledge gap on the interaction of policy and innovation with growth to determine environmental impacts. Third, non-linear and threshold effects may be studied through the lens of various types of pollutants, including particulate matter or water pollution, and may confirm heterogeneous patterns other than those of CO2 emissions. Lastly, the usage of the spatial econometric models may reflect cross-country spillovers and regional interactions which are very important when considering the trade-integrated and geographically proximate developing economies. Taken together, these extensions would improve evidence base of the development of sustainable growth strategies designed to suit the special contexts of developing countries.

References

1. A. Raihan and A. Tuspekova, "Dynamic impacts of economic growth, energy use, urbanization, agricultural productivity, and forested area on carbon emissions: New insights from Kazakhstan," World Development Sustainability, vol. 1, p. 100019, Jan. 2022, doi: 10.1016/j.wds.2022.100019.
2. B. Kahouli, K. Miled, and Z. Aloui, "Do energy consumption, urbanization, and industrialization play a role in environmental degradation in the case of Saudi Arabia?," Energy Strategy Reviews, vol. 40, p. 100814, Mar. 2022, doi: 10.1016/j.esr.2022.100814.

3. Q. Liu et al., "Robust strategies to end global poverty and reduce environmental pressures," One Earth, vol. 6, no. 4, pp. 392–408, Apr. 2023, doi: 10.1016/j.oneear.2023.03.007.
4. A. O. Acheampong and E. E. O. Opoku, "Environmental degradation and economic growth: Investigating linkages and potential pathways," Energy Economics, vol. 123, p. 106734, Jul. 2023, doi: 10.1016/j.eneco.2023.106734.
5. P. H. Leal and A. C. Marques, "The evolution of the environmental Kuznets curve hypothesis assessment: A literature review under a critical analysis perspective," Heliyon, vol. 8, no. 11, p. e11521, Nov. 2022, doi: 10.1016/j.heliyon.2022.e11521.
6. Y. Zhang, "Circular economy innovations: Balancing fossil fuel impact on green economic development," Heliyon, vol. 10, no. 18, p. e36708, Sep. 2024, doi: 10.1016/j.heliyon.2024.e36708.
7. S. Bibi, A. Khan, X. Fubing, H. Jianfeng, S. Hussain, and A. N. Khan, "Impact of environmental policies, regulations, technologies, and renewable energy on environmental sustainability in China's textile and fashion industry," Front. Environ. Sci., vol. 12, Dec. 2024, doi: 10.3389/fenvs.2024.1496454.
8. Q. Wang, Y. Li, and R. Li, "Rethinking the environmental Kuznets curve hypothesis across 214 countries: the impacts of 12 economic, institutional, technological, resource, and social factors," Humanit Soc Sci Commun, vol. 11, no. 1, p. 292, Feb. 2024, doi: 10.1057/s41599-024-02736-9.
9. W. K. Jaeger, V. Kolpin, and R. Siegel, "The environmental Kuznets curve reconsidered," Energy Economics, vol. 120, p. 106561, Apr. 2023, doi: 10.1016/j.eneco.2023.106561.
10. C. Delgado, "Can Developing Countries Cut Emissions Without Affecting Growth," Earth.Org. Accessed: Oct. 03, 2025. [Online]. Available: https://earth.org/how-developing-countries-can-reduce-emissions-without-compromising-growth/
11. I. Savin and J. van den Bergh, "Reviewing studies of degrowth: Are claims matched by data, methods and policy analysis?," Ecological Economics, vol. 226, p. 108324, Dec. 2024, doi: 10.1016/j.ecolecon.2024.108324.
12. N. Saqib, M. Usman, M. Radulescu, C. I. Sinisi, C. G. Secara, and C. Tolea, "Revisiting EKC hypothesis in context of renewable energy, human development and moderating role of technological innovations in E-7 countries?," Front. Environ. Sci., vol. 10, Dec. 2022, doi: 10.3389/fenvs.2022.1077658.
13. M. Mahmoodi and N. Dahmardeh, "Environmental Kuznets Curve Hypothesis With Considering Ecological Footprint and Governance Quality: Evidence From Emerging Countries," Front. Environ. Sci., vol. 10, Mar. 2022, doi: 10.3389/fenvs.2022.849676.
14. Y. Wang and Y. Xu, "Green natural capital, the environmental Kuznets curve and development financing in the Global South," iScience, vol. 27, no. 5, p. 109562, Mar. 2024, doi: 10.1016/j.isci.2024.109562.
15. R. Ghazal, M. S. Karimi, M. Khezri, B. Javaheri, and Y. Bilan, "Unraveling the environmental Kuznets curve: The influence of economic diversity, energy efficiency, and industrial dynamics on carbon emissions in developing economies," Energy & Environment, p. 0958305X241279948, Oct. 2024, doi: 10.1177/0958305X241279948.
16. A. Naveed, N. Ahmad, R. FathollahZadeh Aghdam, and A. N. Menegaki, "What have we learned from Environmental Kuznets Curve hypothesis? A citation-based systematic literature review and content analysis," Energy Strategy Reviews, vol. 44, p. 100946, Nov. 2022, doi: 10.1016/j.esr.2022.100946.
17. S. A. Odei, S. K. Dunyo, and H. J. Anderson, "Research and development, economic growth, CO2

emissions and environmental Kuznets curve," Sustainable Futures, vol. 9, p. 100541, Jun. 2025, doi: 10.1016/j.sftr.2025.100541.