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Testing the Validity of Environmental Kuznets Curve for Carbon Emission: A Cross-Section Analysis

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ABSTRACT

Global warming and its consequences have heightened the urgency of reducing emissions of carbon dioxide globally. The concern arises from countries' relentless efforts to achieve economic development at the expense of the environment. In this context, the paper examines the Environmental Kuznets Curve (EKC) hypothesis at the world level using carbon emission as an indicator of environmental degradation. The EKC hypothesis postulates an inverted U-shaped curve between economic development and environmental degradation; degrading environmental quality at the initial stages of development and, after a threshold level, environmental degradation lowers. The study investigates the validity of the EKC hypothesis for carbon emission with an analysis of 158 countries in the world, with population, urbanization, forest cover, and tourist inflow as the control variables. The study is based on secondary data collected from the World Bank. A regression analysis is used for the study. To ensure environmental sustainability, it is important to identify the determinants of carbon emissions across countries with varying levels of economic development. The findings of the study support the hypothesized inverse U-shaped association between Gross Domestic Product per capita and carbon emission per capita at the world level. Out of the four control variables, urbanization and tourist inflow were found statistically significant. Urbanization was positively correlated with carbon emission per capita while forest area was negatively correlated. Carbon emission per capita initially increases with rising GDP per capita and declines after GDP per capita reaches a certain level. The estimated turning point of GDP per capita occurs at a high level and therefore, most of the countries are anticipated to emit carbon dioxide.

INTRODUCTION

In recent times, issues on global warming and economic development have drawn the attention of the intellectual world towards sustainable development strategies. The countries towards accelerating economic growth often neglect environmental degradation which if not addressed can cause irreparable environmental damage and divert away from sustainability. Therefore, attempts to combat carbon emissions are one of the important challenges for countries across the globe. There are many facets to environmental quality. The air we breathe, the water we drink, the natural beauty we experience, and the variety of species we interact with all have an impact on how we live. Climatic conditions, rainfall patterns, and the nutrient content in the soil all have an impact on how productively our resources produce goods and services. These and other aspects of environmental quality may all react differently to economic growth (Grossman & Kruger 1995).

At the global level, the need to reduce environmental harms by mitigating carbon dioxide emissions the major contributor to greenhouse gas has been realized. The Kyoto Protocol in 1997 under the United Nations Convention on Climate Change (UNCCC) stressed countries to limit and curb their carbon emissions. The United Nations' 2030 Agenda for Sustainable Development Goals (SDGs) and Paris Climate Change Conference, 2015 also allow countries to take up the resolution of cutting their greenhouse gas emissions. The Paris Agreement directs the countries to cut their emission of greenhouse gases to keep the rise in global temperature of this century within 2 degrees Celsius and lower it to 1 degree Celsius. Despite several strategies, the global emission levels are higher to control global warming to 2 degrees Celsius and 1 degree Celsius (UNEP 2019).

Worldwide emission of carbon dioxide, one of the major greenhouse gases is approximately 4.47 metric tons per capita (World Bank 2019). The amount of carbon emission varies over time and across countries. Therefore, identifying the determinants of carbon emission, and the relationship between GDP and carbon emission assumes importance. Carbon emissions have been associated with economic growth which can be explained by the Environmental Kuznets Curve (EKC). According to the EKC hypothesis, in the early stages of economic growth environmental degradation increases which after attaining the threshold level of economic growth reduces gradually. The inverse U shape of carbon emission-induced EKC can be illustrated due to agricultural activities and subsequent shift towards industries leading to more emission of carbon dioxide (Gokmenoglu & Taspinar 2018, Opoku & Boachie 2020). This is called the scale effect and composition effects of economic growth (Murshed et al. 2020). In the later stages of economic growth, improvement in technology, and infrastructure along with environmental consciousness lowers the emission of carbon dioxide. This is called the technique effect.

The Environmental Kuznets Curve (EKC) hypothesis has been largely discussed in the field of environmental economics over the past years. The Environmental Kuznets Curve (EKC) hypothesis has been coined from the Kuznets Curve forwarded by Simon Kuznet that proposed that income inequality widens along the path of economic development in the early stage and improves in the later stages (Kuznet 1955). A seminal work investigated the environmental repercussions of the North American Free Trade Association (NAFTA) taking sulfur dioxide, dark matter, and suspended particulate matter as indicators; and observed that environmental quality does not degrade steadily with economic growth. The study holds that economic growth results in degradation in the early phase but after a certain level of economic growth, environmental quality improves (Grossman & Krueger 1991). Shafik & Bandyopadhyay (1992) observed the relationship between economic growth and environmental quality by assessing the patterns of environmental transformation for countries at different levels of income taking eight indicators of environmental quality. These studies developed the ground for the Kuznets curve hypothesis and the term "Environmental Kuznets Curve hypothesis" was used for the first time by Panayotou in 1993. Several studies establish the validity of the inverse U-shaped relationship between economic growth and environmental degradation. A cross section study of 68 countries both developed and developing with deforestation as an indicator of environmental degradation validated an inverse U-shaped EKC. The turning point for deforestation was estimated between USD800-USD1200 per capita (Panayotou1993). A similar study found an inverse U-shaped relationship between economic development and carbon dioxide emission on a panel of 130 countries from 1951-1986 with USD35428 as the turning point (Holtz Eakin & Selden 1995). EKC for carbon emission was also obtained for OECD countries from 1980-2002 using a fixed effect and random effect approach. The estimated turning point in the study is between USD11152 and USD15949 (Halkos Tzeremes 2009). An inverted U-shaped relationship between tourism and CO_2 emissions was found implying that a nation's emissions initially increase with the tourism industry's growth and decline after reaching the threshold (Jiaqi et al. 2022). Apart from testing the validity of EKC with respect to carbon emission, studies regarding the evidence of EKC across other variables are ample. EKC hypothesis was also evidenced in the rate of water utilization in a cross-section study of 163 countries for the year 2000 (Barbier 2004). Similarly, EKC in case export quality was observed for Bangladesh and India of the five South Asian countries from 1972 to 2014 (Murshed & Dao 2020). A strong relationship between GDP per capita and e-waste generation per capita in the cross-section of 174 countries was observed at the world level and continent level (year 2016). It found the validity of EKC for e-waste at the continent levels for all except for Asia and a turning point at USD 70, 000 (Boubellouta & Kusch-Brandt 2021).

Although several works support the validity of EKC for carbon emission, however some studies do not. For instance, EKC for carbon emissions of 149 countries was not observed from 1960 to 1990 (Shafik & Bandyopadhyay 1992). Another study observed that environmental degradation measured in CO_2 emissions increased with economic growth (Shafik 1994). In a cross-country panel data for 13 OECD countries also did not observe EKC for solid waste (Cole et al. 1997). Similarly, in the panel of 152 countries from 1970-1990 EKC for carbon emission was not established (Magnani 2001). On the other hand, N shaped relationship was observed between economic growth and environmental degradation in Nigeria (Usenobong & Chukwu 2011). A similar observation was found in a study that examined how the per capita water footprint varies with per capita income at both aggregated and disaggregated levels of water footprint using cross-section data. The estimation results give rise, in most cases, to evolution into an N-shaped relationship but provide no support for an inverted U environmental Kuznets curve. The turning point is estimated at USD17,700 and USD40,434 (Sebri 2015). Therefore, the EKC hypothesis for carbon emission remains inconclusive. In addition, the volume of carbon emissions varies across countries and over time. It is unlikely that different volumes of carbon emission are emitted from sources unrelated to Gross Domestic Product if such large differences in growth to development gap between countries. Therefore, in examining the determinants of carbon emission the association between Gross Domestic Product and carbon emission assumes importance. This paper attempts to find the validity of EKC in carbon dioxide emissions of 158 countries. In this study, carbon dioxide emission is conceptualized as an indicator of environmental degradation, and Gross Domestic Product (GDP) as an indicator of economic development. Apart from the cross-country analyses it also incorporates explanatory variables namely, population, urban population, forest cover, and tourist inflow. The EKC hypothesis has been used in several studies to examine the association between environmental quality and economic development. The main purpose of the paper is to identify the factors of carbon emission across countries with different stages of economic development. The paper will be an addition to the literature in the field of an empirical study of the test for the Kuznets curve for carbon emission around the world. The rest of the paper is arranged as follows. Section 2 provides the literature review followed by methodology in section 3. The results are explained in section 4 and conclusions in section 5.

MATERIALS AND METHODS

To fulfill the objectives, the regression model is used to examine the nature of the association between GDP and carbon emission and the factors of carbon emission. To study this at the global level, the sample comprises 158 countries of the world for 2019 based on secondary information for which full data was available. The reference year of the study is 2019 since it is a recent dataset and contains the maximum countries of in the world.

For testing the EKC in the case of South Asian countries (excluding Afghanistan due to insufficient data), data have been obtained for a period between 1990 to 2019 except for Maldives i.e. between 1995 and 2019. All data are obtained from the official database of the World Bank.

Econometric Model

For examining the inverse U-shaped EKC, several studies have incorporated a quadratic term of GDP per capita in the model (Murshed et al. 2020, Boubellouta & Brandt 2021, Mehmood et al. 2022). To examine the inverse U-shaped relationship between GDP and CO_2 emission, the following empirical model is used:

$$\ln CO_2\text{\_em. per capita}_i = \beta_0 + \beta_1 \ln(\text{GDP per capita}_i) + \beta_2 \ln(\text{GDP per capita}_i)^2 + \beta_3 \ln(Z) + u_i \quad \ldots(1)$$

Where, CO_2_em. per capita $_i$ refers to carbon dioxide emission measured in terms of metric tons of carbon dioxide equivalents, GDP per capita $_i$ and GDP per capita $_i^2$ refer to per capita gross domestic product and its squared term respectively measured in constant 2015 US dollar prices. Z is a vector of variables which includes population, urban population, forest cover, and tourist inflow. The population is the total population of the country, urbanization is the percentage of the total population living in urban areas, forest cover is measured as the percentage of land under forest area, and tourist inflow is expressed as the number of tourists arriving in the country.

The coefficients β_1 and β_2 capture the linear and non-linear relationship respectively, i refers to the country and u_i is the error term. For the EKC hypothesis to be valid, the coefficients of β_1 and β_2 should be significantly positive and negative simultaneously. This will indicate the existing inverted U-shaped EKC; carbon dioxide emission increases with GDP per capita and after the threshold level, carbon emission lowers. Thus, to examine this, regression analysis is used. The variables used are in natural logarithms.

The turning point GDP level where further economic growth will not increase carbon emission is calculated as (Cole et al. 1997):

$$\exp\text{-}\ \beta_1/2\ \beta_2 \quad \ldots(2)$$

The econometric software SPSS 22 was used. Ordinary Least Squares regression was used to examine the model. This study uses cross-section data (the year 2019); panel data over several years are not available for countries worldwide. The OLS method has been widely used in previous studies and is a standard method of choice to analyze cross-section data.

Dependent, Independent and Control Variables

This work takes carbon emission per capita as the dependent variable calculated by dividing total carbon emission per year by the total population in each country. Independent variables contain GDP per capita. To test the EKC, i.e., to check whether the relationship between GDP per capita and carbon emission per capita is inverse U shaped, GDP per capita (linear term) and GDP per capita squared (non-linear term) in the econometric model. The association between dependent and independent variables is inverted U-shaped if the estimates of the linear and non-linear terms have positive and negative signs respectively. This will imply that the validity of EKC, which states that carbon emission initially increases with GDP per capita and after reaching the threshold level (turning point), it decreases.

A set of control variables that could influence carbon emission have been included. For instance, population growth is found to be responsible for increasing air pollutants. Population causes pollution as it is associated with the rise in the consumption of energy due to rising industries, transport services, and power demand. It further escalates pollution by large-scale clearing of forests. Population is expected to have a positive relation with carbon emissions. Similarly, urbanization is also anticipated to positively affect carbon emissions. Another factor that is expected to positively affect carbon emissions is tourism. Around 5 percent of global carbon emissions are generated by tourism (Jiaqi et al. 2021). Tourism leads to an increase in demand for transportation, hotels, consumption, and shopping activities which can contribute to carbon emissions. On the other hand, forest cover is expected to be negatively related to carbon emissions. Forests play a vital role in regulating global warming as it acts as a sink of carbon dioxide, the prime pollutant of greenhouse gas emission. Forests in UNESCO World Heritage sites absorb approximately 190 million tonnes of net carbon dioxide emission annually.

RESULTS AND DISCUSSION

For several decades environmental repercussions of carbon emissions have been widely debated. Global warming and climate change are the important consequences of carbon dioxide emission which constitutes the major portion of the greenhouse gas emission. During the last decade, the global surface average for carbon dioxide rose by 2.15 parts per million (NOAA 2023). One of the ways to find the drivers of carbon emissions is to look at GDP values and population figures. Table 1 presents carbon emissions around the world in 2019, fragmented into 7 regions (a list of countries is given in Appendix I). The absolute quantities of carbon emission (metric tons) show that Europe and Central Asia generate the highest carbon emission, followed by North America, while South Asia, and Middle East, and North Africa emit less carbon emission than Europe and Central Asia but more than Latin America and Caribbean and East Asia and Pacific. Sub-Saharan Africa has the lowest carbon emission among all the regions

Table 1 further reveals that the population figures do not have an impact on carbon emissions, in East Asia and Pacific, South Asia, and Sub-Saharan Africa, the populated regions have low emissions of carbon dioxide compared with North America (the least populated region). However, the average carbon emission is higher for regions with high per capita GDP except for Latin America and the Caribbean region. The highest GDP per capita is observed in North America coupled with the highest carbon emission per capita i.e., 14.75 Mt followed by Europe and Central Asia (6.59 Mt), East Asia and Pacific (6.37 Mt), Middle East and North Africa (7841.2394 kg/inh). This reflects that GDP per capita has an impact on the amount of carbon emission per capita and the link between the two has been reported in literature for sets of countries. This may be because increased output requires more input and hence more natural resources resulting in increased pollution.

In the South Asian region, Maldives (3.97 Mt), and India (1.80 Mt) emit carbon dioxide higher than the average of the region as a whole (Table 2). It can be observed that Maldives, the highest GDP per capita in the region generates maximum carbon emission per capita while Afghanistan, the lowest GDP per capita emits less carbon dioxide per capita in 2019. The energy and waste sectors are the prime emitters of greenhouse gases in Maldives (Second National Communication of Maldives to the United Nations Framework Convention on Climate Change 2016).

Table 3 shows the descriptive statistics of the variables- carbon emission, GDP per capita, population, urbanization, forest cover, and tourist inflow. All the variables are for the year 2019. Table 4 gives the correlation coefficients among the variables. This shows that there is a modest positive correlation between GDP per capita and carbon emission per capita. A moderately high correlation exists between GDP per capita and carbon emission per capita with urbanization. A positive correlation exists between GDP per capita, carbon emission, population, and urbanization with tourism. There is no multicollinearity problem as no strong correlation is present among the variables.

Table 5 presents the regression results. The relationship between carbon emission and GDP per capita is studied without control variables in Model 1 and with control variables (population, urbanization, tourist inflow, and forest cover) in the regression model for robust results. Model 1 (excluding the explanatory variables) and Model 2 analyze carbon dioxide emission per capita as the dependent variable. For each model, the turning point is calculated, and since the turning point depends on the estimation method and model specifications, the turning point under model 1 may not be the same as model 2 (extended model). In Model 1, the coefficient of GDP per capita and its squared shows are positive and negative values significant at 1 percent. This implies the presence inverted U-shaped EKC in case of carbon emission. Further, model 2 includes explanatory variables- population, urbanization, forest cover, and tourist inflow to ensure the robustness of model 1. The coefficients of GDP per capita and its square value justify the non-linear EKC for carbon emission. This implies that carbon emission per capita initially increases with GDP per capita and after a certain level of GDP per capita it falls.

The adjusted R^2 of model 2 shows that 84.5 percent variation in carbon emission per capita is explained by population, urbanization, forest cover, and tourist inflow. It is further observed that urbanization and forest cover are significant factors of carbon emission while population and tourist inflow is insignificant. The positive sign of urbanization implies that urbanization leads to more carbon

Table 1: Carbon emissions generated around the world and different regions in 2019.

Indicators	South Asia	Europe and Central Asia	North America	Latin America & Caribbean	Middle East and North Africa	East Asia and Pacific	Sub Saharan Africa	World
Number of countries with sufficient data availability	8	48	2	32	19	29	46	158
Population	1835776769	915718285	365931183	614138933	434954058	2292892002	1092398639	6769930892
Total CO_2 emission (metric ton)	2784080	6033360	5397930	1515650	2518340	14602910	821190	32788560
CO_2 emission per capita (Mt/inh)	1.52	6.59	14.75	2.47	5.79	6.37	0.75	4.84
GDP total (2015 USD)	3419823615667	22277926765204.30	21621599192026.10	5210710532862.06	3410578892388.07	25320593651684.80	1828341243913.62	80149650103828.20
GDP per capita (USD/inh)	1862.88	24328.36	59086.52	8484.58	7841.24	11043.08	1673.69	11839.06

Source: Own calculation using data from the World Bank (2019)

Table 2: Carbon emission among the South Asian countries in 2019.

Country	CO_2 emission per capita(Mt)	GDP per capita (USD/inh)
Afghanistan	0.16	555.14
Bangladesh	0.56	1581.57
Bhutan	1.38	3238.06
India	1.80	1965.54
Maldives	3.97	10197.09
Nepal	0.47	1069.79
Pakistan	0.88	1497.99
Sri Lanka	1.09	4228.15
Total	1.52	1862.88

Source: World Bank (2019)

emissions. The negative sign of forest cover indicates the beneficial role of forests with respect to curbing carbon emissions across the world.

Although the estimated coefficients of GDP per capita and GDP per capita square on carbon emission per capita slightly reduced after including population, urbanization, forest area, and tourist inflow, there is still a quadratic relationship between and strong relationship between GDP per capita and carbon emission per capita at 1 percent level of significance. This implies that carbon emission per capita initially increases with the rise in GDP per capita and declines after GDP per capita attains a certain level. This validates the hypothesis that EKC between carbon emission per capita and GDP per capita. In addition, this relationship appears robust since similar results are obtained from both models.

The EKC turning points vary from USD69831.9 GDP per capita and USD56499.61 GDP per capita for model 1 and model 2 respectively. In the sample of 158 countries, three countries have exceeded the turning point GDP per capita of USD69831.9 (Ireland, Luxembourg, and Norway) while eight countries have exceeded the turning point of USD56499.61 (Australia, Czechia, Iceland, Ireland, Luxembourg, Norway, Singapore and USA).

Moreover, two diagnostic tests were applied to ensure the appropriateness of the model. First, Durbin-Watson statistics have been used to check the possibility of autocorrelation. It is observed that the value is closer to 2 in both the models which reject the presence of autocorrelation. Secondly, the Bruesch-Pagan test is used to check for heteroskedasticity. The result of the Bruesch-Pagan test is insignificant; therefore there is no heteroskedasticity in both the models. The high adjusted R^2 and significant F-statistics justify the overall goodness of the models.

CONCLUSION

During the last few decades, there has been growing concern about the impact of carbon dioxide on the environment

Table 3: Descriptive statistics of 158 countries.

Variables	Mean	Maximum	Minimum	Standard Deviation	N
lnGDP per capita	8.79	11.59	6.04	1.31	158
lnCO_2 emission per capita (in metric tons)	0.84	3.09	-2.98	1.30	158
lnPopulation	15.65	21.07	9.36	2.20	158
lnUrbanization (in % of urban population)	3.99	4.61	2.58	0.46	158
lnTourist inflow	14.82	19.20	8.19	2.07	158
lnForest cover (in % of land)	14.82	4.58	-4.82	1.41	158

Note: Figures are rounded to the nearest hundred

Table 4: Correlation Matrix.

Variables	lngdp_percapita	lnco$_2$_percapita	lnpopulation	lnurbanisation	lntourist	lnforest
lngdp_percapita	1					
lnco$_2$_percapita	0.87*	1				
lnpopulation	-0.11	-0.06	1			
lnurbanisation	0.64*	0.63*	0.12	1		
lntourist	0.55*	0.56*	0.56*	0.48*	1	
lnforest	-0.00	-0.07	-0.10	-0.09	-0.07	1

Note: * denotes significance at 1 percent level.

Table 5: Results of OLS regression with $lnCO_2$ emission per capita (metric ton) as dependent variable.

Variables	Model 1	Model 2
Intercept	-20.486*	-20.726*
lnGDP per capita	4.060*	3.961*
lnGDP per capita^2	-0.182*	-0.181*
lnPopulation		0.033
lnUrbanization		0.228***
Lnforest area		-0.101***
lntouristinflow		-0.047
R^2	0.834	0.852
Adjusted R^2	0.832	0.845
F-statistics	389.711*	123.348*
Turning point	69831.9	56499.61
N	158	158
DW statistics	1.9	2.1

Note: *, ** and *** denote statistical significance at 1%, 5%, and 10% respectively.

and human health. The paper examined the validity of CO_2-induced EKC at the world level and in seven South Asian countries along with the drivers of carbon emission at the world level. To analyze the relationship between carbon emission and GDP with respect to EKC, by adding variables like population, urbanization, forest cover, and tourist inflow were assessed. The findings show that EKC for carbon emission is valid at the world level implying that initially, carbon emission per capita increases with rising GDP per capita, and eventually falls after reaching the threshold level. The turning point of GDP per capita (for the world sample) is high for most of the countries. Only eight countries have surpassed the estimated turning point GDP per capita Australia, Czechia, Iceland, Ireland, Luxemburg, Norway, Singapore and the USA. A strong relationship between GDP per capita and carbon emission was found at the world level. It is observed that urbanization and forest cover influence the link between GDP per capita and carbon emissions. Urbanization has a positive effect on carbon emissions which is due to the fact of increasing consumption of goods and services, infrastructure development, and land use ultimately degrading the environmental quality. On the other hand, the forest was negatively associated with carbon emissions implying that countries with larger forest areas have lower carbon emissions. Therefore, it throws light on the need for urban planning to build a sustainable environment for the cities. A negative sign effect of forest cover on carbon emission directs the significant role of trees in reducing carbon emissions and combating the problem of global warming.

Based on the empirical findings of this study, the following are a few recommendations:

1. The study establishes the validity of EKC for carbon emission across the world and turning points at high GDP per capita levels. Carbon emissions will continue for many years before any decoupling of carbon mission and economic growth is likely to occur. This emphasizes the need for effective implementation of policy to fasten the decoupling. Thus, it would be unjustified to rely on reducing the amount of carbon emission as like EKC effect.
2. The results show that urbanization and forest cover are important determinants of carbon emissions. Therefore, policy directions for curbing carbon emissions for improving environmental quality should consider these two factors in policy measures. This calls for the need for the countries to concentrate on green economies and designing a sustainable plan for urban development. Growth strategies need to align with the environmental welfare policies whereby the macroeconomic factors resulting in carbon emission are taken care of for instance energy diversification in a way of shift towards alternative renewable energy resources.
3. The study found a negative correlation between forest area and carbon emission which signifies the crucial role of forest in combating global warming. Forests absorb huge amounts of carbon dioxide which if destroyed can be a source of greenhouse gas. Countries should take incentives to check on deforestation. Recently, as a part of the Paris Agreement countries have established the 'REDD+' (Reducing Emissions from Deforestation and Forest Degradation in developing countries) framework to protect the forests.

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