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THE EKC HYPOTHESIS IN BRICS-4 COUNTRIES AND USA: A NOVEL SECOND-GENERATION PANEL DATA ANALYSIS.

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Abstract*:* This paper establishes the long run association between gross domestic product (GDP) and gross fixed capital formation (GFCF) with carbon emission (CE) in BRICS-4 countries and USA. To empirically estimate the long run cointegration and to check the validity of EKC hypothesis, the novel second-generation panel data analysis is done by taking the annual data from 1991-2020. All the variables are cross-sectionally dependent, differenced stationary, and cointegrated over the long run, according to empirical estimations of CD-LM test, CADF & CIPS tests, and Westerlund (2007), respectively. Moreover, the coefficients estimated by employing the novel DCCE approach validates the presence of the EKC hypothesis in the BRICS-4 countries and the USA. Finally, based on the empirical findings, this paper posited some valuable policy recommendations for the BRICS-4 countries and USA.

Keywords: Carbon Emission, Economic Growth, Environmental Kuznets Curve, Second-Generation Panel Data Analysis.

JEL Codes: F64, C01, Q56, Q54

1. Introduction

The deteriorating environmental circumstances have massively increased concern about climate change and global warming, highlighting the connection between expanding energy use, pollution, and economic growth. Even though global warming is caused by anthropogenic gas emissions, the repercussions vary by country due to socioeconomic and environmental factors, which were found the main cause of global warming climate instability (Houghton, 1996). The United Nations Framework Convention on Climate Change's most recent accord (UNFCCC, 2017) digital Conference in Glasgow 2021, known as Paris Agreement drew unprecedented contribution from world leaders to achieve consensus by 2020-2030 on legally requisite greenhouse gas emission reductions of methane up to 30% and other gases up to 50% to safeguard the environment for both the present and future generations by taking action that might greatly increase the economic sustainability (Michaelowa, 2021).

A data release by International Energy Agency draws eyes opening attention towards carbon emission and other energy related greenhouse gas emission over the past years. The Global emission of carbon only from energy incineration and industrial progressions reflections in 2021 were noted the highest ever increase in annual rate of carbon release in decade. Only in 2020 to 2021 a 6% increase causes 36.3 gigatons (Gt) releases in carbon emission due to the increment in global economic production by 5.9% which were noted as the highest amount carbon emission with GDP growth since 2010 results were based on region-by-region, fuel-by-fuel energy consumption (Newell et al, 2021).

Rise in global warming and climate change brought attention of the world to combat and discuss the global environmental issues (Ipek, 2022). Air pollution, change in ocean temperature, disappearance and melting of glacier, delay in seasons effecting global average rise in sea level are several concrete evidence of global warming. The Paris agreement has decided to cope the climate change under the banner of international treaty on climate change due to the global increase in carbon emission (Shaikh, 2020). Which were functionally adopted by 196 countries to fight against increasing climate change under the banner of National Determined Contributions (NDCs) to cut the global emission by 45% from 2019 to 2030 as zero-carbon solutions (Arora & Mishra, 2021). The primary focus was to adopt and implement the best available technologies to achieve economic and social transformation for future generations.

The novel COVID-19 pandemic has impacted the economy globally (Shaikh, 2021) and emission caused by human were affected the rise of anthropogenic emission in early mid of 2020. Therefore, the report of EDGAR 2020 noted a decline trend in carbon emission by 5.1% lower (Crippa et al, 2021). According to Emission Database for Global Atmospheric Research (henceforth, EDGAR) world largest carbon emission released in total by these 6 major world economies (such as, China, USA, EU27, Japan, India, and Russia), were 66.7% global fossil fuel related carbon emission emitted in total where the global share of GDP is 61.8%, while total global fossil fuel consumption noted as 65.2% in 2020. During the COVID-19 pandemic an increasing trend of carbon emission in China was noted at 30.34%, while others noted a decrease, like, USA at 9.9%, the EU27 at 10.6%, India at 5.9%, Russia at 5.8%, and Japan at 6.8% decreases their emission respectively (Monica et al, 2021). The crux of the discussion, how high-polluting economies might decrease GHG emissions without impeding their productivity expansion has been discussed at the Cancun 2010 Conference on

Climate Change. The primary energy consumption by fuel of world largest 6 countries show a decreasing trend from 2019 to 2020 noted as, where China (26.1%), USA (15.8%), EU27 (10%), India (5.7%), Russia (5.1%) and Japan (3.1%) (Ahmed & Zhang, 2020).

From the statistical discussion above these countries are of the largest carbon emitter in the world which a largest of the world economy as well. Therefore, it will be reasonable to check the EKC hypothesis in these countries by assembling their data. Moreover, the investment spendings defines the future production therefore, along with gross domestic product, we must consider the relationship between gross fixed capital formation and the carbon emission in the light of EKC hypothesis as well.

The purpose of this study is to investigate the impact of carbon emission on the economic growth performance among the selected countries. Various researchers examined the effect of economic growth on carbon emissions in various nations because of the increase in carbon emissions, but their studies did not come to the same empirical conclusions. The reason for this non-similarity can be because of different economic level of the countries or the different types of statistical modes which have been used in previous studies. Thus, the main reason of this study to find the precise empirical results based on new research technique and methods. Main aim of this paper is to identify the relationship between economic growth and carbon emission under EKC hypothesis in BRICS 4 countries and USA which are largest emitter of carbon, as we saw in the discussion above.

To understand the economic growth structure to emit the carbon emission at a different time scale is the main part of this chapter in the perspective of world climate change mitigation. To find the relationship between economic growth and carbon emission, the gross fixed capital formation as an important economic indicator is preferred. Since investment spendings defines the future production level which thereby defines the carbon emission level.

At (UNFCCC, 2017), USA, China, and India had agreed to reduce the greenhouse emission by half till 2030 and the follow-up meeting were digitally organized in Poland in 2020 (USA withdrew from that meeting), where growing economies requested to submit their report by 2023 of carbon mitigation policy implementation in both short and long run. Therefore, the importance of climate change and the rising economic growth at the expense of environment, were the main objectives of this research to be considered as an important player, especially on BRICS-4 countries and USA due to their unregulated economic growth and neglection of problem of carbon emission.

2. Theoretical Background and Framework

Environmental pollution in the past decade raises the concerns of the world's thinktank to adopt the sustainable policies and technologies to cope and combat anthropogenic gas emission without any further damage of planet earth (Cook, et all., 2013). However, Grossman and Krueger's research of the North American Free Trade Agreement (NAFTA) in 1991 gave birth to the concept of the "Environmental Kuznets Curve" (Hervieux & Mahieu, 2014). Grossman and Krueger noted in their research paper titled as " North American Free Trade Agreement", they discovered that the concentrations of two pollutants, sulphur dioxide and smoke, increase with rising levels of gross domestic product per capita and low levels of national income while decreasing with high levels of per capita income and growth in gross domestic product (Krugman, 1992).

The general idea of the EKC hypothesis is commonly applicable in a broad perspective literature to examine the effect of economic growth and capital formation on environment sustainability (Nasir & Rehman, 2011). After a certain point, as per capita growth increases, environmental quality improves due to the gradual awareness brought through the application of environmental degradation regulations, improved infrastructure, advanced technology, and investments in environmental education. Environmental degradation increases in parallel with increase in income level (Panyato, 1993).

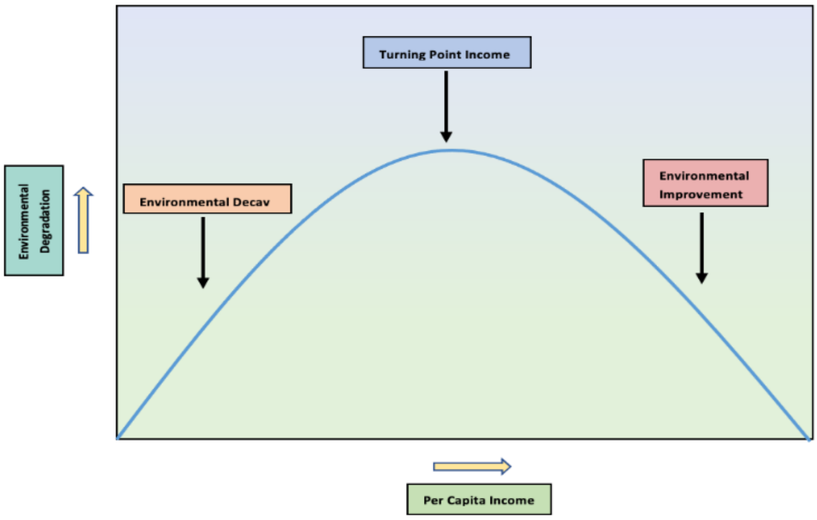
The EKC relationship's theory is naturally influential. Although, due to industrialization, the population rises rapidly due to high emphasize priorities the material outcome and individual are more concerned towards job which provide income than that of healthy ecosystem (Dasgupta et al., 2002).

The study borrows the approach employed by (Wang et. al, 2011), (Ang, 2007) and the panel data analytical framework proposed by (Apergis & Payne, 2009). Following (Wang et. al, 2011), (Ang, 2007) and (Apergis & Payne, 2009), we established the long-term relationship between carbon emissions (GFCF) and gross fixed capital and gross domestic product (real GDP) in BRICS-4 countries and USA. Environmental Kuznets Curve hypothesis in its original form can be mentioned as follows:

$$E = f\ (X, Y, \Delta N) \qquad (1)$$

In the above equation "E" represent as environmental indicator, "X" represent as an economics growth indicator, "Y" represent as a gross capital formation and "ΔN" represent as explanatory variable characteristics that might affect environmental degradation We did not include any other additional variables in our model because the primary objective of this research is to examine the causal link and cointegration between economic growth, gross capital formations, and carbon emissions. Figuratively, EKC curve is described as shown below. It shows that, initially, environmental degradation and economic growth are positively related, therefore we see an increasing graph up to optimum. Later, after the economic growth reach certain level, the environmental degradation begins to decline with further increase in output levels. Indicating that, with increase in income and output level of an economy, the through environmental protection policies and adoption of energy efficient technologies, the environmental degradation shows negative relationship with economic growth.

The EKC hypothesis represent a profound dynamic process of change in income level of a country over a period as shown in figure above. Where level of anthropogenic gas emission goes up and after threshold limit of income start declining in long run. It's a trajectory of an economy that goes through multiple stages of development can be observed empirically with cross-economy and cross-sectional stats represents income groups response to pollution (Stern, 2004).



Source: Author Calculation

Figure 1. Environmental Kuznets Curve

It was observed that there was a u-shaped association between income inequality and per capita (Hao et all., 2016). Therefore, the distribution of income shift towards equality as economic growth pattern carried out, initially it has been noted rise in the patter of income inequality but has been settled in later. Although, developed countries has confirm that the rise in per capita income reduce the level of environmental degradation due to the awareness came with income towards pollution and healthy environment (Brannlund & Ghalwash, 2008). In case of developing and under developing economies sustainable globalization noted to be more efficient in generating per capita income and eradicating income inequality (Borghesi & Vercelli, 2013).

Moreover, environmental degradation found to have an inverted U shape correlation with growth rate. Therefore, increase in growth rate reduces the impact of environmental degradation in any economic activity (Stem et al., 1996). Individuals possess a higher standard of living as their earnings grows and they become more interested in the quality of the ecological system. This desire for a better environment may lead structural changes in the economy, which tend to lessen ecological damage (Roca, 2003). Furthermore, increasing per capital income rises the demand of pollution free environment, where elasticity of environmental standard identified and to keep it environmentally friendly with the income elasticity is less than one percent (Barbier et. al, 2017).

Bulte & Soest (2001) constructed a model to understand the depletion of natural resources, therefore suggestion for global procurement of resource and shifting industries where sufficient resources available for manufacturing. Essential transformation in energy-intensive technology from coal to gas, fossil fuel to solar energy and wind energy and low sulphur coal to high sulphur coal has already contributed to the reduction of emission (Gielen et al., 2019).

Growing trade is a significant factory for creating emission in developing countries for production and consumption emission, non-energy-intensive manufacturing and production of trade goods and services (Peters et al, 2011). Foreign direct investment played one of the major roles in any developing or under developing economy to combat anthropogenic gas emission. To attract FDI, developing economies can drop and regulate their environmental standard to create a pollution heaven (Jiang et. al, 2018). Also, international, and national non-governmental organizations, financial institutions, industrialist, investors, environmental activist, environmental regulator, policy maker and citizens can make a huge impact to adopt carbon-intensive policies to combat harms caused by growth of emission (Pearse & Bohm, 2014).

2. Impact of Carbon Emissions on Various Economic Indicators

(Azam et. al, 2016) discovered that energy use and carbon emissions significantly harmed economic growth. (Al-Mulali & Sab, 2012) researchers found that an increase in economic activity is leading to a greater emission of carbon.

(Wan et al, 2022) found that growing wealth inequality can reduce energy use and boost R&D spending, which will help to reduce CO_2 emissions. Whereas (Halicioglu, 2009) concluded in the study that there exists an interchangeable between income inequality and carbon emission. Furthermore, it was shown that rising income levels are contributing to an increase in carbon emissions, but declining economic activity will result in higher unemployment and lower income.

Li & Lin (2013) study's findings led to the conclusion that per capita income significantly reduced carbon emissions. (Salahuddin et. al, 2018) observed that increasing demand of energy consumption is causing and impacting negatively on carbon emission. (Ahmad et. al, 2021) noted that the balance of trade is impacting positively on carbon emission in under developing and developing countries. (Baloch et al, 2020) asserted that there was a negative correlation between poverty and carbon emissions. (Yao et. al, 2020) stated that the human capital standard is negatively impacting carbon emission and environmental pollutions. (Yumashev et. al, 2020) study focused on human development index impact on carbon emission and found that the HDI has been a major factor and impacting on carbon emission depending on the GDP and research and development expenditure. (Wang et. al.,2021) in their study they noted that there is a trade-off between life expectancy and carbon emission since it was found that urbanization cause higher CO_2 emissions which cause rise in unemployment level, population density and lower economic growth rate while increase in growth rate contribute to lower carbon emission.

Table 1. Summary of Impact of Carbon Emissions on Economic Indicators

Authors	Research Object	CO2 vs	Impact
Al-Mulali & Sab (2012)	Sub Saharan African countries	Economic Growth	Negative
Azam et. al (2016)	China, USA, India & Japan	Economic Growth	Negative
Halicioglu (2009)	Turkey	Income Inequality	Interchangeable/Trade-off
Wan et all (2022)	217 countries	Income Inequality	Negative
Li & Lin (2013)	110 countries	Per Capita Income	Positive
Xie et. al (2020)	Emerging 11	FDI	Positive
Salahuddin et. al (2018)	Kuwait	Energy Consumption	Negative
Ahmad et. al (2021)	Pakistan	Balance of Trade	Negative
Baloch et. al (2020)	Sub-Saharan African countries	Poverty	Negative
Yao et. al (2020)	20 OECD Countries	Health or Human Capital	Negative
Yumashev et. al (2020)	28 OECD countries	HDI	Negative
Wang et. al (2021)	154 countries	Life Expectancy	Negative

3. Literature Review

The Environmental Kuznets Curve (EKC) and economic growth literatures were utilized to demonstrate a link between carbon dioxide emissions, GDP ($) growth, and real output (Kuznets, 1955). The literature on real GDP ($), carbon emissions, and economic growth is organized by (Magazzino, 2014b). However, the electricity demand-GDP nexus is outlined in (Magazzino, 2014a) and (Payne, 2010).

Magazzino (2014) the relationship between Economic Growth, CO2, and EC within the 6 ASEAN countries from 1971 to 2007 is examined using a VAR panel technique, emphasizing the statistically substantial positive response of Economic Growth and Energy. Between 1971 and 2007, it was discovered that there was a positive correlation between the calculated coefficients and impulse responses between economic growth, carbon dioxide emissions, and energy use.

Murshed et al. (2020) in South Asia from 1980 to 2016, used "cross-sectionally dependent heterogeneous panel data with structural breaks" to examine the EKC hypothesis for the consumption of liquefied petroleum gas by using the CCMG and AMG model technique. The research's empirical findings support the EKC theory, and as a result, CCMG and AMG estimates found that LPG use significantly increases greenhouse gas emissions across all economies.

Cheikh et al. (2021) examines the nonlinear correlations between energy use, CO2 emissions, and level of income within 12 MENA nations between 1980 and 2015. The empirical model employed was PSTR to understand the relationships among, CO2, income level as GDP proxy, EC. Therefore, empirical estimates obtained were indicated the validity of EKC hypothesis in MENA countries.

Pandey & Mishra (2015) did a study to examine the relationship between SAARC countries' economic growth and carbon emissions using the panel VAR approach and found with 1% increase in GDP is causing 1.83% decrease in Carbon emission.

Usman & Jahanger (2021) for 93 nations between 1990 and 2016, research was done on the varied effects of remittances and institutional quality in the reduction of the environmental deficit under the notion of the EKC hypothesis. The empirical estimates of the PQR model, indicated the significantly positive effects on environmental degradation by the inflow of remittances and GDP.

Liu et al. (2019) conducted research on 125 countries to analyses the export diversification, CO2 emission and EKC over a period of 2000-2014. They have used export diversification, GDP and CO2 variables for fixed effect model for high-income level and random effect model for low-income level OECD countries. EKC hypothesis were found valid for the panel. The FEM an REM estimates noted that negative relationships indicating that export diversification export products diversification both improve the pollution level for panel.

Akdiri et al. (2021) conducted research on an economic freedom verses economic development perspective within BRICS for the period of 1995-2018. They have adopted an empirical approach of PMG-ARDL to analyze the relationship between GDP, CO2, economic freedom, HDI, Coal, natural gas, and oil. The PMG-ARDL estimates denoted economic freedom is significantly and negatively related to emission. Thus, they have concluded that while economic expansion may, in the short term, raise emissions, it may also contribute to long-term increases in income levels and economic development. Therefore, their empirical estimates validate the EKC in BRICS for long-run.

Yigiti (2021) conducted an empirical study in the D-8 countries between 1990 and 2014 using panel VAR analysis to determine the relationship between carbon release and energy consumption and found that the D-8 countries' energy use and carbon emissions support economic growth.

Saboori et. al (2012) conducted a study in Malaysia to examine the connection between economic growth and CO2 emissions. To examine the long-term causal link for the years 1980 through 2009, the environmental Kuznets Curve hypothesis underwent a cointegration analysis and a relationship in the U shape was found between the chosen variables in both the long run and the short run.

Mulali et. al (2015) studied 18 Latin American and Caribbean nations between 1980-2010 by applying Vector Error-Correction Model (VECM). The Fully Modified Ordinary Least Squares (FMOLS) model was employed to examine the impact on the relationships between the log-runs of the selected variables. The EKC theory was supported by estimates from the FMOLS model that indicated an inverted U-shape link between GDP and carbon emissions.

Bilgili et. al (2016) forecasted research on how usage of renewable energy affects CO2 emissions dynamically by using panel data for 17 OECD nations from the years 1977 to 2010. A revised Environmental Kuznets Curve technique was adopted to estimate the model. The FMOLS model's estimates revealed a positive correlation between carbon emissions and GDP. The EKC hypothesis was thus proven to be essentially accurate for the 17 OECD nations.

Ahmad et. al (2017) did a study to investigate the association between CO2 emission and economic growth in Croatia between 1992Q1 and 2011Q1. The ARDL limits test was used to ascertain cointegration between the variables. As a result, it was identified and demonstrated that EKC is ultimately quite legitimate for Croatia.

Cowan et. al (2014) using a panel causality model, this study examined the causative link between energy use, economic expansion, and carbon emissions in the BRICS countries during 1990–2010 time-period. The neutrality hypothesis applied to Brazil, China, and India whereas the conservation hypothesis applied to Russia and South Africa. According to the study's empirical evidence, it was found that Brazil, China, and India have little influence on either electricity consumption or economic growth. According to the panel granger causality test, unidirectional causality between GDP and CO2 was discovered in South Africa, but unidirectionality between CO2 and GDP was discovered in Brazil. Furthermore, China and India failed to find a link between GDP and CO2 that was causative. On the other hand, the growth in carbon dioxide (CO2) emissions in South Africa, Brazil, China, or Russia was unrelated to the consumption of energy. As a result, we can draw the conclusion that the estimates do not yield consistent granger causality results. Accordingly, the authors claimed that uniform policy recommendations cannot be made for the BRICS countries to stop environmental degradation.

Rastegaripour et. al (2019) conducted research on the link between CO2 emissions, energy consumption, and economic growth in Iran during 1997–2019 periods. The Generalized Method of Moments (GMM) estimates provided by the Two Stage Least Squares equation demonstrated that a 1% increase in energy consumption results in a 0.37% gain in GDP whereas a 1% increase in CO2 results in a 0.03% reduction.

Mercan & Karakaya (2015) studied the empirical association between energy consumption, economic growth, and carbon emissions for selected OECD nations from 1970 to 2011 using dynamic panel cointegration analysis. The estimates resulted that the energy usage among OECD countries has a progressive influence on carbon release with a marginal wounding shock on gross domestic growth in long-run.

Table 2. Summary of Literature Review

Authors	Country	Period	Variables	Methodology	Conclusion
"Saboori et al. (2012)"	"Malaysia"	"1980-2009"	GDP, CO2,	ARDL	EKC valid
Mulali et al. (2015)	Latin America & Caribbean Countries	1980-2-10	GDP, REC, CO2,	VECM	EKC valid
"Bilgili et al. (2016)"	17-OECD	1977-2010	GDP, REC, CO2,	FMOLS, DOLS	EKC valid
Murshed et al. (2020)	South Asia	1980-2006	GDP, GHG, LPG, TOP, FDI,	CCMG, AMG	EKC valid
Cheikh et al. (2021)	MENA	1980-2015	GDP, CO2, EC,	PSTR	EKC valid
Ahmad et al. (2017)	Croatia	1992-2011	GDP, CO2,	ARDL, VECM	EKC Valid
Usman & Jahanger (2021)	93-Countries	1990-2016	GDP, EF, TOP, URP, EC, FDI, IQ,	PQR	EKC valid

Liu et al. (2019)	125-Countries	2000-2014	Export diversification, CO2, GDP,	FEM, REM	EKC valid
Akdiri et al. (2021)	BRICS	1995-2018	GDP, EF, CO2, HDI, Coal, Gas, Oil	PMG-ARDL	EKC valid in Long-term
Magazzino (2014)	6-AESEAN	1971-2007	GDP, CO2, EC,	VAR, IRF	Positive relationship among GDP and CO2
Pandey & Mishra (2016)	SAARC	1972-2010	GDP, CO2,	VAR, VECM	EKC valid
Yigit (2021)	D8- Countries	1990-2014	RGDP, CO2, EC,	VAR,	One-way causality found between GDP and CO2
Cowan et al. (2014)	BRICS	1990-2010	GDP, CO2, EC,	Panel Causality	Unidirectional relationships among GDP to CO2 and CO2 & EC found negative relationships
Rastegaripour et al (2019)	Iran	1997-2019	GDP, CO2, EC	GMM	Bi-directional relationship among GDP, CO2, and EC
Mercan & Karakaya (2015)	OECD	1970-2011	GDP, CO2, EC,	CDLM	Positive relationship among EC and CO2

4. Data and Model

The relationship between CO2 and financial inclusion has been examined for the BRICS-4 (Brazil, Russia, India, and China) countries as well as the USA for the years 1991 to 2020 in this paper. The study has employed carbon emission (CE) as a dependent variable while Gross Fixed Capital Formation Growth (GFCF) and Gross Domestic Product (GDP) as the independent variables.

Table 3. Data Source & Description

Variables	Description	Unit	Form	Source
CE	Carbon Emission (2017)	Percentage	-	World Bank
GDP	Real Gross Domestic Product	Level	Natural Logarithm	World Bank
GFCF	Gross Fixed Capital Formulation	Level	Natural Logarithm	World Bank

Source: (World Bank, 2022)

5. Correlation Matrix

Correlation matrix defines the degree of correlation between the variables. For our model the correlation matrix is given below.

Table 4. Corelation Matrix

Variables	**CE**	**LnGDP**	**LnGFCF**
CE	1.00	-0.16	-0.05
LnGDP	-0.16	1.00	0.97
LnGFCF	-0.05	0.97	1.00

The table above, shows the coefficient of correlation among the variables under consideration, which has a varies between -1 to +1, with -1 indicates a strongly negative connection and +1 indicates a strongly positive correlation. From the table we can see that carbon emissions shows negative correlation with gross domestic product. On the other hand, it shows positive correlation with gross fixed capital formation.

6. Descriptive Statistics

Descriptive statistics defines the general statistical information about the individual variables, such as mean, standard deviation, kurtosis, skewness etc.

Table 5. Descriptive Statistics of the Variables

Descriptive Statistics	**CE**	**LnGDP**	**LnGFCF**
Obs.	150	150	150
Max.	1.30	30.69	29.47
Min.	0.12	26.00	24.06
Mean	0.43	28.27	26.85
Std. Dev.	0.25	1.30	1.39
Skewness	0.97	0.32	0.24
Kurtosis	3.62	1.91	1.92
Jarque - Bera	26.36	9.98	8.68
J-B prob.	0.00	0.00	0.00

The table above represents the descriptive statistics of the variables of BRICS-4 countries and USA considered for our model and empirical study later.

The data of all the variables of these BRICS-4 countries and USA has 150 number of observations. The data for gross fixed capital formation, gross domestic product, and carbon emissions are centered over 0.43, 28.27, and 26.85 percent, respectively. The statistic standard deviation which measures the spread or the dispersion of the dataset of CO2, GDP, and gross fixed capital formation, in relation to its mean is 0.25, 1.30, and 1.39 respectively.

The skewness is a statistic which measures the presence of asymmetry in the distribution of the dataset around its mean. For a normally distributed series, the value of skewness is zero. Therefore, the right/left side of the distribution may have a lengthy tail, according to the positive/negative values of skewness. As a result, the long tail on the right side of the distribution is visible for carbon emissions, gross domestic product, and gross fixed capital formation.

The kurtosis is a statistic which measures the presence of peaked-ness or the flatness of the distribution of the series. For a normally distributed series the value of Kurtosis statistic is 3. Therefore, the estimated Kurtosis values of all the variables shown above indicates the presence of normally distributed peaks.

After estimating that the distribution has skewness as well as peak, it is indicated that the series distribution is normal. The Jarque-Bera probability confirms the presence of normal distribution in all the dataset from 1991 to 2020.

7. The Econometric Model

The CO2 emission in any economy is closely associated with either a possible increase in the value of growth or more efficient use of existing Trade and GFCF factors (Akalpler & Hove, 2019). For BRICS-4 countries and USA, the rate of carbon emission is generally dependent on the share of GDP and GFCF, therefore, this study evaluates a model to investigate the impact of investment spendings (GFCF) and real GDP on Carbon emission of BRICS-4 countries and USA. The econometric model of this paper is as follows:

$$CE = f\,(LnGDP, LnGFCF) \qquad (2)$$

Following, (Wang et. al, 2011), (Ang, 2007) and (Apergis & Payne, 2009), the main assessment of the econometric model can descriptively be written in the mathematical form in the following manner:

$$CEit = \alpha it + \alpha 1GFCFit + \alpha 2GDPit + \varepsilon it \quad (3)$$

where i=1, 2,…,N, represents countries taken in the panel, whereas, t= 1,2,3,…T represents the time period of the panel. C represents the carbon emission rate, G represents the real GDP, and Y represents the gross fixed capital formation (GFCF). The parameters $\alpha 1$, and $\alpha 2$ represent the long-run elasticities of real GDP and GFCF, respectively. The main task is to estimate these parameters through novel panel data techniques. As expected under the EKC hypothesis, it is postulated that $\alpha 1>0$ while $\alpha 2<0$.

Thus, we have two hypotheses for this chapter.

Hypothesis 1: GFCF is positively associated to carbon emission in long run for BRICS-4 countries and USA.

Hypothesis 2: GDP is negatively associated to carbon emission in long run for BRICS-4 countries and USA.

Hypothesis 3: GFCF and GDP combined follows the EKC hypothesis.

Considering the approach mentioned in EKC figure discussion of theoretical background, our hypothesis of this chapter focuses on two indicators. The real GDP and the investment spending in the form of GFCF. Since the GDP demonstrates long-term economic indicator and GFCF demonstrates the short-term economic indicator, so, in our framework, real GDP must be negatively related to carbon emissions, and it is investment spendings that must define the negative relationship with carbon emissions. Hence, together they must follow the EKC hypothesis.

8. Methodology

A second-generation panel data approach was used in this thesis for Brazil, China, India, Russia, henceforth, BRIC countries. Latest advancement in the econometric techniques has been advancing the research on panel data methods considering cross-section dependency. We have adopted the advanced panel data techniques in these studies described in subsections. Cross-section dependence test, first and second generations panel unit root test, first and second-generations panel cointegration test, and lastly the novel dynamic common correlated effects to estimate the coefficients followed by homogeneity test make up the remaining steps of the thesis.

9. Cross-sectional Dependence Test

In a panel data analysis, the cross-sectional dependency test in the series is a crucial step. If a researcher does not consider the CD in the series, the results of the investigations could be deceptive and erroneous. (Dogan et al., 2017). To define whether cross-sectional dependence exists in the panel, we run numerous series of tests, including the CD test and the Lagrange multiple (henceforth, LM) test, the scaled-LM test, and the adjusted scaled-LM test. The LM test homogeneity method as proposed by Breusch and Pagan (Breusch & Pagan, 1980). However, the CDLM1 test produces biased findings when the group mean is zero and the unit mean deviates from zero. CDLM1 can be employed when the panel is considerably larger than the cross-section size (N), while CDLM2 was created by (Pesaran, 2004). The large period (T) and relatively small cross-sections are suitable for this test (N). When the mean pairwise correlation is near to zero, this test will not be effective (Pesaran, 2004). By including both the variance and mean to the test statistics, (Pesaran et al. 2008) created a bias-adjusted test of cross-sectional dependence (LMadj) to address this flaw.

The bias-adjusted LM test is presented below.

$$Bias - corrected\ Scaled\ LM = \sqrt{\left(\frac{1}{N(N-1)}\right)}\ \sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T_{ij}\widehat{P_{ij}^2} - 1) - \frac{N}{2(T-1)} \quad (4)$$

The usual normal distribution for the CD test is asymptotic. The alternative hypothesis of cross-section dependency is tested in this study against the null of no cross-section dependency.

Therefore, the second-generation panel unit root test must be employed if the cross-section dependency is discovered in the series.

10. CIPS Panel Unit Root Test

The CIPS test of second-generation panel unit roots. Additionally, it uses the cross-sectionally augmented Dickey-Fuller (CADF) test proposed by "Pesaran (2007) to examine variable stationarity. Specifically, the test estimates CADF test statistics for each unit of the panel before acquiring the cross-sectionally augmented Im-Pesaran-Shin (henceforth, CIPS) test, which uses the typical value, or the arithmetic mean, for the entire panel with CADF estimates, due to the unobserved common component identified by the test, cross-section dependence develops. Therefore, this test validates in both conditions for both "$N > T$ and $T < N$" (Guloglu and Ivrendi, 2008). The mean of the CADF test estimates refers to the CIPS test which is as follows:

$$\text{CADF} = t(N,T) = \frac{\Delta y_i^l\ \bar{M}_i y_{i-1}}{(\Delta y_{i\text{-}1}^l\ \bar{M}_i y_{i-1})^{1/2}} \quad (5)$$

which is transformed into CIPS by averaging it as described below.

$$CIPS\ = N^{-1}\sum_{i=1}^{n} t(N,T) \quad (6)$$

When estimated CIPS values exceed the critical table values, a variable is regarded as panel stationary (Katircioglu et al. 2015).

In order to do this, we adhere to the second generation cointegration tests provided by Westerlund (2007).

11. Panel Cointegration Test

Due to the first-generation co-integration tests' deceptive results, which overlook several crucial problems including heteroskedasticity, CDS, and serial correlation (Xue et al. 2021) the second-generation cointegration test (Westerlund, 2007) test is more accurate because it accounts for all the aforementioned problems, including serial correlation, heteroskedasticity, and CDS.

The variables CO2, GDP, and GFCF were tested for cointegration using the Westerlund (2007) ECM panel cointegration tests. The alternative hypothesis is that there is cointegration among the panel, while the null hypothesis is that there is no cointegration.

This test is used to determine whether the error-correction term for a conditional panel correction model is equal to zero. This test examines if a group mean has an error correction (G_τ and G_a) and for panel (P_τ and P_a). Following equation represents the Westerlund (2007) cointegrating equation for our study as follows:

$$\Delta CO_{2,i,t} = \alpha_i^C + \lambda_i^C\left(CO_{2,it-1} - \beta_i^C GDP_{2,it-1} - \gamma_i^C GFCF_{i,t-1}\right) + \sum_{j=1}^{m}\theta_{i,j}^G\,\Delta CO_{2,it-j} + \sum_{j=1}^{n}\delta_{i,j}^G\,\Delta GDP_{it-j} + \sum_{j=1}^{p}\emptyset_{i,j}^G\,\Delta GFCF_{i,t-j} + \mu_{i,t} \quad (7)$$

12. Slope Heterogeneity Test

The homogeneity slopes test, which was proposed by (Pesaran &Yamagata, 2008) determines whether slope heterogeneity exists in the model and to determine which estimated model is the best choice. The homogeneity test approach is based on Swamy (1970), which estimates the ($\widehat{\Delta}$) delta and to adjusted delta ($\widehat{\Delta}_{ad}$) to analyze the null theory of homogeneity, H_0: $\lambda_i = \lambda$ in favor of economic homogeneity and opposed to the opposite argument for economics that tends toward heterogeneity, H_1: $\lambda_i \neq \lambda_j$ based on the supposition that there is a non-zero proportion between each pair of variables that can be located anywhere for $i \neq j$. A test Statistics are as follows:

$$\hat{\Delta} = \sqrt{N}\left(N^{-1}\hat{H} - \frac{1}{2l}\right) \sim X^2{}_l \qquad \text{(H)}$$

$$\hat{\Delta}_{ad} = \sqrt{N}\left(N^{-1}\hat{H} - \frac{l}{SE(T,l)}\right) \sim N\,(0,1) \qquad \text{(SE)}$$

In the above-mentioned equation, *N* represents the "number of cross-sections, *l* indicates the number of independent variables, *H* denotes the heterogeneous test statistic, and *SE (T, l)* is the demonstration of the errors in a standardized form. A larger sized sample (whole data set) is estimated through Eq. (H), whereas small sample-sized samples (ER sample, CR sample, and WR sample) are estimated in the Eq (SE)".

13. Dynamic Common Correlated Effects (DCCE) Estimation Test

The Dynamic Common Correlated Effects estimation approach, which was created by Chudik and Pesaran (2015), was used in this study to elaborate on the CD issue that was not addressed in prior models that provide biased estimates. (Ditzen, 2018) expanded the DCCE approach of (Chudik & Pesaran, 2015) for the heterogeneous panel estimating outcomes for both short- and long-term estimations. As a result, it was inevitable that the DCCE approach would address several critical issues, many of which were either disregarded or went undetected in the previous methodologies, as was evident from the results of many studies.

The principal goal of this model was to identify the causes of variables on each other in BRICS-4 countries and USA for carbon emission by using carbon emission as a dependent variable and GDP and GFCF as our independent variables. The model's specifications were elaborated in a pragmatic manner that was appropriate.

In order to comply with the model specifications, the DCCE equation stated below can be written.:

$$Y_{it} = a_i Y_{it-1} + \delta_i X_{it} + \sum_{P=0}^{PT} \gamma_{xip}\,\overline{X_{t-P}} + \sum_{P=0}^{PT} \gamma_{yip}\,\overline{Y_{t-P}} + \mu_{it} \qquad (8)$$

In the equation above, "the dependent variable and its lag are both present. Y_{it} represent as dependent variable while its lag is denoted by Y_{it-1}, and X_{it} represents the independent variable, subscripts *I* and *t* show cross-sectional and time dimensions". "The common unobserved factors are expressed by γ_{xip} and γ_{yip} and *PT* and μ_{it} shows the lag of cross-sectional averages and the error term". By adding the ecological footprint as a dependent variable, we have significantly expanded our variables for the Carbon emission (Pollution heaven BRICS-4 countries) hypothesis (Carbon emission).

$$YCO_{2,it} = a_i CO_{2,it-1} + \delta_i X_{it} + \sum_{p=0}^{pT} \gamma_{xip}\,\overline{X_{t-p}} + \sum_{p=0}^{pT} \gamma_{yip}\,\overline{Y_{t-p}} + \mu_{it} \qquad (9)$$

The above equation, $a_i CO_{2,it-1}$ is the log of ecological footprint (carbon emission) used as the dependent variables, $\delta_i X_{it}$ indicates the set of independent variables log like LnGDP, and LnGFCF are reported by the X_{it}.

14. Empirical Estimates

In this subdivision, the study details the empirical findings obtained and discusses the results. We begin with conducting, first, the cross-section dependent test to confirm cross-sectional dependency, second, panel unit root tests to check stationarity at first difference, third, long run cointegration test to check the presence of long run association between the taken variables. Fourth, we estimate the coefficients by employing the novel "Dynamic Common Correlated Effects:" Mean Group and Pooled methods. Finally, fifth, we test for heterogeneity of the slope coefficients, using the slope homogeneity test. Hence, the estimates of each test mentioned above are as follows.

15. Cross Section Dependence Test

Initially, study conducts the CD tests among the series to examine the cross-sectional dependency and indicate which unit root must be conducted. The study considered the outcome of the empirical findings of the bias-corrected scaled LM test. Moreover, the study includes the findings of Pesaran- CD, and Pesaran scaled LM tests.

Table 6. Cross Section Dependence Test

Variable	**Pesaran-CD**		**Pesaran-scaled LM**		**Bias-corrected scaled LM**	
	Stat.	**p-value**	**Stat.**	**p-value**	**Stat.**	**p-value**
CE	7.69	0.00*	31.98	0.00*	31.90	0.00*
LnGDP	15.75	0.00*	53.47	0.00*	53.38	0.00*
LnGFCF	14.78	0.00*	47.20	0.00*	47.12	0.00*
					Breusch-Pagan LM	
Model	1.76	0.05**	26.36	0.00*	127.89	0.00*

Note: *, ** and *** demonstrate the level of significance at 1%, 5% and 10%, respectively.

The findings of the CD tests give sufficient evidence to reject the null hypothesis no cross-sectional dependency across the BRICS-4 countries and USA. Depending on the empirical outcomes of the cross-section dependency examined in the series, in next section of the study, we conducted a second-generation panel unit-root test named as CIPS and CADF.

16. Panel Unit Root Tests

The second-generation panel unit root predicts that each unit may not be analogously affected by economic shocks (Taylor & Sarno, 1998; Breuer et al, 2002; Pesaran, 2007; Hadri & Kurozumi, 2012;). Hence CIPS and CADF tests are employed in our study.

Table 7. IPS, CIPS, and CADF Unit Roots Tests

Variables	**CIPS**		**CADF**	
	I(0)	**I(1)**	**I(0)**	**I(1)**
CE	-2.19	-4.54*	-1.63	-2.69*
LnGDP	-2.04	-3.77*	-2.14	-2.76*
LnGFCF	-2.18	-3.66*	-1.77	-3.06*

Note: *, ** and *** demonstrate the level of significance at 1%, 5% and 10%, respectively.

The values of CIPS, and CADF test statistics for all the variables are less than the critical table values. All other test statistics showing non-stationarity of the variables at level; however, all the variables are found to be stationary at first difference with 1% statistical significance. Since, our variables are differenced stationary, therefore, we can test for long run cointegration among them (Tari & Abasiz, 2010).

17. Panel Cointegration Test

The second-generation panel cointegration tests is performed that allow for cross-sectional dependence for all the variables of the considered model (Westerlund & Edgerton, 2007).

Table 8. Westerlund (2007) ECM Panel Cointegration Test Results

HO: no cointegration	**Value**	**Z-value**	**P-value**
Gt	-2.42	-2.23	0.01*
Ga	-8.85	-1.23	0.00*
Pt	-5.23	-2.36	0.00*
Pa	-10.02	-3.43	0.00*

Note: *, ** and *** demonstrate the level of significance at 1%, 5% and 10%, respectively.

The p-values of Gt, Ga, Pt, and Pa statistics are less than 1% which implies there is statistically significant long-run cointegration between the variables such as Carbon Emission, Gross Domestic Product and Gross fixed Capital Formation of BRICS-4 countries and USA between the 1991-2020 time-period.

18. Slope Heterogeneity Test Results

To check if the slope coefficients of our model are heterogenous, we applied slope homogeneity test. The null hypothesis for the underlying test indicated that the slope of the cointegration equations does not differ among cross-sections of the panel (Pesaran &Yamagata, 2008).

Table 9. Slope Heterogeneity Test Results

H0: slope coefficients are homogenous	**Delta**	**p-value**
	20.78	0.00
Adj.	20.32	0.00

As shown in table above, the null hypothesis is rejected since, all the probabilities are statistically significant at 1% which is indicating that the country specific constant terms and slopes coefficients are heterogenous and therefore we adopt the novel Dynamic Common Correlated Effects to estimate our coefficients since it allows for heterogenous slope coefficients. The findings of our test are consistent with (Chaudhry et al, 2022).

19. Dynamic Common Correlated Effects Estimates

The novel Dynamic Common Correlated Effects estimated results of our econometric model for BRICS-4 countries and USA, are presented in the table down below. The value of lags for the dependent variables (CE,) in this research is associated significantly with their explanatory variables i.e., LnGFCF, and LnGDP.

Table 10. DCCE- Pooled Mean Group & Mean Group Estimates

	Pooled Mean Group		**Mean Group**	
D.CE	Coef.	p-value	Coef.	p-value
L.CE	-0.30	0.00	-0.31	0.00
LnGDP	-0.10	0.10***	-0.13	0.00
LnGFCF	0.08	0.10***	0.06	0.03**
_cons	-2.81	1.00	0.50	0.50

Note: *, ** and *** demonstrate the level of significance at 1%, 5% and 10%, respectively
Mean Group Variables: L.CE, LnGDP, LnGFCF
Cross Sectional Averaged Variables: D.CE, L.CE, LnGDP, LnGFCF

Empirical finding of the research using DCCE model, where both PMG and MG statistics indicate that the economic growth i.e., LnGDP has the negative and statistically significant relationship with carbon emission of BRICS-4 countries and USA between the years 1991 to 2020. Therefore, it has given the indication that the economic growth and carbon emission both are negatively related with each other, which indicates that the increase in GDP will decrease the CE in BRIC countries. The empirical findings accept, first hypothesis of this chapter, and "the results of the research are aligned with", (Dogan et al, 2017) where their findings suggested that the increase in GDP is reducing carbon emission in OECD countries and (Saint et al, 2019) where it was also found that Carbon Emission and GDP are inversely related to each other. Additionally, "these findings are also supported" by (Yalcinkaya et al, 2017).

Conversely, we have found that the LnGFCF (also called investment) is showing "statistically significant positive relationship with carbon emission" indicating that with increase in gross fixed capital formation, carbon emission has also been rising. "These findings are consistent" with the (Bekhet et. al, 2017) where GFCF was found to be positively related with carbon emission and the accepts, second hypothesis of this chapter. Additionally, the empirical findings of (Khan et al, 2020) also supports our estimates since their results indicate that GFCF is positively related to Carbon emission. Thus, acceptance of the first two hypotheses leads to accepts the third hypothesis which validates the EKC hypothesis in BRICS-4 countries and USA.

20. Conclusion and Policy Recommendations

This paper investigates the relationship between carbon emission as dependent variable with gross domestic product and gross fixed capital formation as independent variable in the BRICS (excluding South Africa) countries and USA between 1991-2020 time-period by adopting a novel approach known as the Dynamic Common Correlated Effect (DCCE) model to check the validity of EKC hypothesis. Since all the variables showed cross-sectional dependence, therefore, both CIPS and CADF unit roots test showed that all the variables are differenced stationary. Also, the Westerlund (2007) tests showed that all the variables, i.e., carbon emission, gross domestic product and gross fixed capital formation are cointegrated in the long run. Moreover, the slope homogeneity test indicated that the country specific slope coefficients are heterogenous. Thus, the empirical estimates of the DCCE method indicated that gross fixed capital formation is increasing the carbon emission in BRICS-4 countries and USA meaning that, GFCF and CE are positively related. As a result, our first hypothesis, that GFCF and CE have a positive long-term relationship is confirmed. However, it is discovered that the gross domestic product and carbon emissions are inversely associated, supporting the second hypothesis from our first study. The acceptance of the first two hypothesis of our study eventually leads to the acceptance of the third hypothesis which results in the validation of EKC hypothesis in the BRICS-4 countries and USA.

Since GFCF is the component of expenditure on GDP and the validation of EKC hypothesis through positive relationship between GFCF and CE is an indication that investment spendings in these countries are playing major role in creating the carbon emission than the economic growth. Hence, based on these statistically significant empirical findings, we can put forward several policy recommendations for the policymakers. First, they must be careful while making future investments, since GFCF is basically the investment spendings, therefore, policymakers must design policies in such a way that future investment spendings in done on environmentally friendly technologies and industries. Second, the GFCF can also be directed towards the sustainable development programs, such as adoption of renewable energy resources, production of efficient machineries, and raising awareness about environmental protection.

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