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Testing for the existence of the Environmental Kuznets Curve (EKC) in developed, developing and least developed countries: evidence from the Granger Causality Test

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Thank you

This paper marks the end of my studies, which have been full of ups and downs, but here we are. And I say we because it would never have been possible without certain people whom I would like to thank. To begin with, I'd like to thank my mum and my dad, my number one fans, who have always pushed me to give the best of myself, never giving up despite the difficulties. Next, I'd like to thank my thesis supervisor, without whom this work would never be, Dr. Jean-Baptiste Hasse, who always showed me kindness, availability, help and encouragement. He fulfilled his role as supervisor like no other and I am honoured and grateful to have had the opportunity to work with him. I would also like to thank Prof. Bertrand Candelon for proofreading and revising this work.

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Table of Contents

Introduction

Context Description

The relationship between economic growth and the environment has been a topic of study and debate for a very long time. Early economic theories frequently viewed the environment as a free good with no economic value, therefore it wasn't something that needed to be considered while making economic decisions. However, as the detrimental impacts of economic activity on the environment became more apparent and as the economic value of environmental resources and services became more generally understood, the relationship between economic growth and the environment started to receive more attention (Everett et al., 2010).

In the 1970's, the term "sustainable development" initially appeared to think about how to strike a balance between the need for economic advancement and the need to protect the environment for future generations (Ginting 2019). In fact, in 1972, the Conference on the Human Environment in Stockholm, Sweden spotted the relationship between environment and development. But it is the Brundtland Commission which was established by the UN in 1983 that provided a definition of that concept, stating that "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Johnston et al, 2007). This marked the beginning of the concern about the link between environment and economic growth.

Then, the concept of "green growth" appeared in 2005 at the Fifth Ministerial Conference on Environment and Development (MCED). The objective being to go beyond the sustainable development and pursue a green growth. That concept evolved and different definition have been given to what green growth is. But the main idea remains the same, increase economic growth while minimizing its negative environmental repercussions. There is still ongoing discussion about how to balance environmental preservation and economic growth. While some argue that economic expansion and environmental protection are incompatible, others argue that both can be achieved through the adoption of sustainable practices and green technologies (World Bank, 2012).

Traditionally, there has been a widely held belief that as a country's economic activity grows, so does its carbon emissions. The wealthier a country becomes, the more CO_2 it tends to emit due to the reliance on fossil fuels for energy in production processes. However, numerous countries have managed to decrease their greenhouse gas emissions while simultaneously increasing their GDP. The USA being one those countries. This transition has gained momentum, characterized by a shift from carbon-intensive industries to services and a transition from fossil fuels to more affordable green energy sources.

In addition, the escalation of CO_2 emissions stands as a primary contributor to the climate change predicament. The pursuit of economic growth necessitates extensive energy usage, leading to increased CO_2 emissions. Consequently, pollution becomes intrinsically connected to economic growth and development. However, economic growth and development also foster the introduction of innovative energy-saving and low-carbon technologies that replace outdated, energy- and carbon-intensive counterparts (Kasperowicz, 2015).

As a matter of fact, the highest absolute decline in CO_2 emissions ever was witnessed in 2020 as a result of worldwide lockdowns due to the Pandemic COVID 19. With the suspensions of aircraft, surface transportation, power production, and industrial, global fossil CO_2 emissions fell significantly. However, as of 2021, emissions had increased, which was close to pre-pandemic levels. And while, CO_2 emissions from developed countries are stabilizing, the emissions from developing economies seem to increase.

Paris Agreement

COPs (Conference of the Parties) are the most significant annual climate conferences worldwide. In 1992, the United Nations organized the Earth Summit in Brazil, where the United Nations Framework Convention on Climate Change (UNFCCC) was adopted as the coordinating agency. The treaty aimed to "stabilize greenhouse gas concentrations in the atmosphere to prevent dangerous interference with the climate system caused by human activities."[1] To date, 197 different parties have signed this agreement. Since the treaty came into force in 1994, the UN has convened annual COPs, bringing together nearly all nations to address global climate issues.

During these gatherings, countries have engaged in negotiations to establish legally binding emissions limits, leading to extensions of the original treaty. Examples include the Kyoto Protocol in 1997 and the Paris Agreement adopted in 2015. The Paris Agreement saw all countries committing to intensify their efforts to limit global warming to 1.5°C above pre-industrial levels and strengthen financing for climate action.

[1] United Nations - Cops

The climate crisis is the result of global inaction, and it has a high cost. The 27th summit or COP27 that took place in Egypt in 2022 was crucial for the health of the entire world. Overall, it is estimated that the climate crisis has resulted in the loss of one-fifth of the gross domestic product (GDP) in the most climate-vulnerable countries. This highlights the significance of acknowledging the damage inflicted upon least developed and developing nations. Throughout the Industrial Revolution, North America and Europe have been responsible for 62% of carbon dioxide emissions, while Africa's contribution stands at a mere 3%. However, concern for Africa extends beyond moral obligations. The severe and ongoing consequences of the climate catastrophe give rise to issues such as conflict, forced migration, infectious diseases, and poverty, which permeate global networks. The goal of climate summits is to quickly cut emissions and limit global temperature increases to 1.5°C or less.

Pricing carbon

With the climate crisis, some countries have tried to find ways to limit their CO2 emissions. During the early 21st century, several countries, including Canada, Ireland, and Sweden, introduced a carbon-tax system that mandates businesses to pay taxes based on the carbon content of the fuels they use. Conversely, countries in the European Union opted for the European Union Emissions Trading Scheme (ETS), a market exchange system allowing firms to trade emission rights. Indirect carbon dioxide taxation through energy and motor vehicle taxes was also prevalent in many countries in the Organisation for Economic Co-operation and Development (OECD) and Eastern Europe.

For economists, climate change is a challenge, and it is of importance to evaluate policy tools to mitigate its consequences. Candelon et al. (2023) evaluate the impact of the Kyoto Protocol, the Swedish carbon tax, and the EU ETS on carbon emissions reduction in Sweden. And the empirical results suggest that only the carbon tax has a long-term impact on reducing carbon emissions.

The economic theory of externalities forms the basis for carbon taxes. When a company emits carbon dioxide, it creates a negative externality that imposes costs on society due to environmental damage. Carbon taxes aim to internalize these costs by implementing a market-based approach. The idea is that once companies are required to bear a portion of the externality expense, emissions will decrease. Moreover, such a tax incentivizes businesses to invest in eco-friendly renewable energy sources, thereby reducing reliance on fossil fuels in the economy.

Research Question

The link between economic growth and CO_2 emissions has been extensively studied in recent decades. Achieving a stable economic growth while protecting the environment is today the concern and a challenge of many countries given the climate change crisis. The purpose of this thesis is to study the validity of the claims of the Environmental Kuznets Curve when dealing with developed, developing and least developed countries over a period from 1960 to 2021. The Environmental Kuznets curve theory states that growth is harmful to the environment in the early stages of development. Initially, environmental quality deteriorates as income rises. From a certain level of wealth, economic growth is accompanied by an improvement in the state of the environment. That is, society will have the means and the will for a healthier environment, which leads to higher standards and improved environmental quality in certain areas. As economic development is the main driver of carbon emissions, it is important to analyse the link between them. (He, Z. & Wei, L. & al, 2023.). To do so, this study will test the relationship between the CO_2 emissions and the GDP per capita when facing different type of countries with different growth and compare the results of the estimations.

Therefore, this study aims to provide an answer to the following question:

"How different is the relationship between CO_2 per capita and GDP per capita in developed, developing and least developed countries?"

However, the limit of this study stands in the face that only six countries have been considered and the data used are from 1960 until 2021. Therefore, we can affirm that this study is limited in time and space. To provide an answer to that research question, this paper is organized as follow: a review of the literature, a presentation of the empirical methodology, the analysis, the results, further analysis and finally the conclusion.

Literature Review

This section is divided into different parts. To begin with, an introduction which will provide a general view of the issue related to economic development and environment. Then, the state of industrialisation. But most importantly, this literature review will advance our knowledge of the connection between economic development and environmental deterioration, particularly the link between CO2 emissions and GDP per capita in developed, developing and least developed countries. Finally, it will discuss how the EKC hypothesis has been applied to study this relationship.

Introduction

As nations pursue economic development and strive for progress, they inevitably face the challenge of unintended environmental consequences. Among these challenges, one of the most significant for policymakers is the issue of greenhouse gas emissions, specifically carbon dioxide (CO2), which plays a central role in driving climate change. While there is a widespread acknowledgment of the necessity to curb emissions to mitigate the detrimental impacts of climate change, there remains ongoing debate and varying perspectives on the intricate relationship between economic growth and CO2 emissions (Htike et al, 2022).

Researchers have devised diverse theoretical frameworks to gain deeper insights into the relationship between economic growth and environmental deterioration. One of the most prominent theoretical frameworks is the Environmental Kuznets Curve (EKC) theory. According to this hypothesis, as countries attain higher levels of economic prosperity, they initially experience an increase in environmental degradation. However, at a certain income threshold, a reversal occurs, leading to a decline in environmental degradation (Uddin, 2021).

The EKC hypothesis has garnered significant attention among scholars, policymakers, and the general public. It has been applied to investigate various environmental issues, including CO2 emissions. The framework's ability to shed light on the complex dynamics between economic expansion and environmental concerns has sparked substantial interest and serves as a significant area of study in academic research.

The relationship between CO2 emissions and GDP per capita is intricate and subject to variation. It is widely recognized that economic growth plays a significant role in contributing to greenhouse gas emissions through energy-intensive industries and transportation systems. However, the connection between CO2 emissions and GDP per capita is influenced by additional factors such as population growth, urbanization, and technological advancements. These elements can further shape and influence the relationship between CO2 emissions and the economic prosperity of a nation (Voumik et al., 2022).

Industrialization

The history of the connection between the economy and the environment is long and complicated. As social orders developed and economies turned out to be more industrialized, the connection between the climate and the economy changed. The social and economic transformation that shifts a society from a primarily agricultural and handicraft-based economy to one dominated by industry and machine manufacturing is known as industrialization.

Industrialization frequently prompted the double-dealing of regular assets and the contamination of the climate. As a rule, financial development and ecological insurance were viewed as being in conflict with one another. It was believed that environmental protection would impede economic growth because it would require the use of resources and the release of pollutants.

However, there has been a growing recognition over the past few years that environmental protection and economic growth can and should go hand in hand. As a result, several policies and initiatives have been developed to encourage sustainable development, which seeks to strike a balance between environmental, social, and economic issues (Avenyo et al., 2021).

There are numerous approaches to sustainable development, all of which acknowledge the significance of safeguarding the environment and preserving natural resources for future generations. Climate change, resource depletion, and pollution are some of the most important issues in the relationship between the environment and the economy.

Many countries' economies have grown significantly as a result of industrialization, particularly during the 19th and 20th centuries. Industrialization has the potential to boost demand for goods and services, create employment opportunities, and raise living standards in addition to boosting economic growth and productivity (Kniivilä, 2017).

Industrialization has spread due to a variety of factors, including technological, communication, and transportation advancements, the availability of natural resources and capital, the interest in labour and products. Economic expansion, an increase in output, and an improvement in standard of living have frequently occurred in tandem with industrialization. However, industrialization has also had ill effects on certain groups of people and the environment. Pollution of air, water and land, resource depletion, and labour exploitation are a few of the negative effects of industrialization (Maurya et al., 2020). All in all, industrialization has played a big role in economic development but also has had an impact on environment.

The Environmental Kuznets Curve

The framework

The Environmental Kuznets Curve (EKC) serves as a theoretical model employed to examine the relationship between economic growth and environmental degradation. According to the EKC, as countries progress and their wealth increases, their environmental conditions initially worsen but eventually begin to improve after reaching a specific income level (Kijima et al., 2010). Grossman and Krueger (1991) pioneered the shape of an inverted "U," with income displayed on the x-axis and environmental quality on the y-axis.

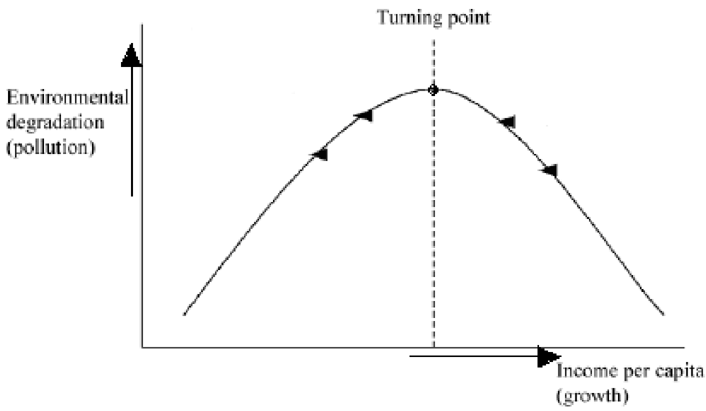

Figure 0: Environmental Kuznets Curve[2]

The EKC has found extensive application in various environmental concerns, encompassing air pollution, water pollution, and greenhouse gas emissions like CO2. Specifically, regarding CO2 emissions, the EKC proposes that as countries experience economic prosperity, they initially

[2] Source : https://earthbound.report/2014/03/11/the-environmental-kuznets-curve/

observe a surge in emissions owing to heightened energy consumption and increased demands for transportation and industrial output. Nevertheless, once a particular income threshold is surpassed, nations may begin transitioning towards cleaner technologies and renewable energy sources, subsequently resulting in a decline in CO2 emissions. (Churchill et al., 2018)

Despite receiving criticism for oversimplifying the complex relationship between economic growth and environmental degradation, the EKC retains its importance as a valuable instrument for analysing the potential catalysts and outcomes of this association. Through the examination of the EKC within diverse country contexts, scholars can acquire significant understandings regarding the interdependence of economic advancement and environmental welfare. Consequently, this enables them to pinpoint potential policy measures that can facilitate sustainable development.

Furthermore, the EKC framework has evolved over time, and various studies indicate that the shape and timing of the curve can vary depending on the specific environmental issue under investigation, as well as other factors such as a country's institutional framework and policy context. For instance, research conducted by Zhang et al (2019) discovered that while the EKC pattern holds for CO2 emissions in most developed countries, it is less pronounced in developing nations. This suggests that developing countries may encounter greater challenges in reducing emissions as they continue to experience economic growth. The EKC framework has also been utilized by other researchers to investigate the impact of specific policies on environmental well-being, such as renewable energy policies, carbon taxes, and emissions trading systems. For instance, a study conducted by Sadorsky (2020) analyzed the influence of renewable energy policies on CO2 emissions in a selection of OECD countries. The findings of their study revealed a positive correlation between renewable energy consumption and environmental quality, thus supporting the EKC hypothesis.

Influencing factors

A consequent number of studies and research have been conducted to investigate the factors influencing the CO2 emissions. In his paper, AhAtil et al. (2019) mention economic growth, energy use and urbanization. Wang et al. (2019), regional agglomeration. Qu et al. (2019), industrialization, industry structure and income level. These are only a few factors from the literature. However, numerous studies have indicated that economic activities play a significant role in influencing CO2 emissions, while technology is viewed as a crucial factor from both positive and negative perspectives.

Wang et al. (2019) conducted a study utilizing panel quantile regression to examine the impact of technological progress in China. Their findings revealed that the influence of technological progress on CO2 emissions varies across different economic sectors. They also observed that technological progress has diverse effects on different emitters, particularly in terms of moderating energy intensity.

Shafik and Bandyopadhyay (1992) conducted an analysis using data from 149 countries spanning the years 1960 to 1990. They discovered a positive correlation between CO2 emissions and income per capita. Li et al. (2011) supported the existence of an inverse U-shaped relationship between economic growth and CO2 emissions. Their findings indicated that as economic growth progresses, CO2 emissions initially increase and then decrease. Wang et al. (2005) examined Chinese data from 1957 to 2000. Their research suggested that energy intensity at a technical level plays a significant role in reducing CO2 emissions, whereas economic growth leads to an increase in CO2 emissions. Wei and Yang (2010) analysed provincial data for China from 1997 to 2007. They observed that economic growth, industrialization, and trade liberalization can contribute to higher CO2 emissions, while technological progress can help in reducing CO2 emissions. Grossman and Krueger (1991) examined the economy-environment relationship and found similarities to the Environmental Kuznets Curve (EKC). They established a linear association between income per capita and CO2 emissions, while the quadratic form had a negative impact, confirming the EKC hypothesis. Subsequent studies using different methodologies, data sets, and pollution indicators have yielded inconsistent and contradictory findings. Alam et al. (2016), Li et al., (2016) support the EKC hypothesis, while others Amri, (2017), Ozturk and Al-Mulali, (2015), Adu and Denkyirah (2018) reject it, using diverse contexts and data types.

As for the factors influencing the inflection point of the Environmental Kuznets Curve (EKC), Jian and Yu (2010) found the growth of economy scale, economic mix, and finally environmental control factors. The literature on the Environmental Kuznets Curve (EKC) in different country contexts delves into the nuanced factors influencing the shape and timing of the curve. While the fundamental EKC hypothesis posits an initial deterioration followed by an improvement in environmental quality with economic growth, the reality is far more intricate, with countries experiencing diverse trajectories of environmental degradation and improvement. In essence, the literature recognizes the need to consider institutional and governance factors as key determinants in understanding the dynamics of the EKC across different countries. By incorporating these factors into the analysis, researchers can gain deeper insights into the intricate relationship between economic growth and environmental quality.

Further expanding on the role of institutions and governance in shaping the EKC curve, an advanced-level study conducted by Martinez-Zarzoso and Bengochea-Morancho (2004) focused on the specific case of CO2 emissions in Latin American countries. Their findings highlighted the substantial influence of governance quality and institutional development in determining the shape of the EKC curve.

According to the study, countries with superior governance structures exhibited a more distinct and accelerated shift towards cleaner economic growth, as indicated by a steeper decline in CO2 emissions. The authors argued that countries with better governance systems are more capable of implementing effective environmental policies and adopting advanced technologies aimed at reducing emissions. This enhanced capacity to address environmental challenges leads to a faster and more pronounced transition towards sustainable economic growth.

In addition to institutional and economic factors, the literature recognizes various other factors influencing the shape and timing of the EKC curve. These include demographic factors, technological change, and globalization. For instance, a study by Zhang et al. (2019) identified urbanization as a critical factor in driving the EKC curve for CO2 emissions in China. The study revealed an initial increase in emissions during the urbanization process, followed by a subsequent decline as the country shifted towards a more service-oriented economy.

To summarize, the nature of the economic growth, plays an important role when it comes to shaping the EKC. In addition, demographic factors, technological advancements, and globalization are additional factors influencing the curve's trajectory.

The relationship between CO2 per Capita and GDP per capita

In developed countries

Research examining the correlation between CO2 emissions per capita and GDP per capita has primarily concentrated on developed nations. Developed countries possess higher levels of economic growth and possess more established institutions, governance structures, and infrastructure, all of which can impact their environmental policies and their ability to mitigate environmental harm. Consequently, scholars have aimed to comprehend the connection between CO_2 emissions per capita and GDP per capita within these countries, aiming to identify factors that either contribute to or hinder environmental preservation.

Findings from studies investigating the link between CO_2 emissions per capita and GDP per capita in developed countries have yielded diverse outcomes. Some studies propose an inverted U-shaped association between the two variables, aligning with the Environmental Kuznets Curve (EKC) theory. These studies argue that as countries experience economic prosperity, they become better equipped to invest in cleaner technologies and implement stricter environmental regulations, resulting in a decline in CO_2 emissions per capita. On the other hand, other studies suggest that there is no clear-cut relationship between the two variables or that the relationship is nonlinear and varies based on the country and its unique circumstances.

A study conducted by Cole and Neumayer (2004) investigated the association between CO_2 emissions per capita and GDP per capita in 36 OECD countries from 1960 to 1997. The findings of the study supported the Environmental Kuznets Curve (EKC) hypothesis, revealing a U-shaped relationship between the two variables. Additionally, the study identified a turning point on the curve, indicating that emissions began to decline at a relatively high level of GDP per capita. This suggests that countries needed to achieve a certain level of economic development before effectively addressing their environmental concerns. Another study by Jorgenson and Wilcoxen (1993) focused on the relationship between CO_2 emissions and GDP per capita in the United States spanning from 1900 to 1988. In contrast to the previous study, this research found no distinct relationship between the two variables, indicating that economic growth does not necessarily result in increased CO_2 emissions. The study further revealed that changes in energy intensity, technology, and fuel mix played significant roles in explaining the variations in emissions over time.

The study by Cole and Neumayer (2004) supported the U-shaped pattern described by the EKC hypothesis, emphasizing the importance of reaching a certain level of economic development before effectively addressing environmental concerns. In contrast, the study by Jorgenson and Wilcoxen (1993) found no clear relationship between GDP per capita and CO_2 emissions in the United States, highlighting the significance of factors such as energy intensity, technology, and fuel mix in understanding changes in emissions.

Studies examining the link between CO_2 emissions per capita and GDP per capita in developed countries employ various methodological approaches, including econometric models, time-series analysis, and panel data analysis. These approaches enable researchers to account for additional factors that may influence the relationship, such as population growth, energy consumption, and technology.

In developing countries

When it comes to developing countries, the relationship between the two variables is not clear. The main findings indicated that there is a positive relationship between income (GDP per capita) and CO2 emissions. This implies that as income levels increase, CO2 emissions also tend to increase, and the Environmental Kuznets Curve (EKC) hypothesis, which suggests an inverted U-shaped relationship between income and environmental degradation, does not hold in the case of some developing countries such as in Kazakhstan (Hasanove et al., 2019).

The study suggests that due to Kazakhstan's status as a developing energy-rich economy, it will take a considerable amount of time and development for the country to reach a stage where income levels lead to a decrease in CO2 emissions. The analysis indicates a monotonically increasing relationship between income and CO2 emissions, emphasizing the need for a more sustainable approach to economic growth. Overall, the study concludes that income has a positive impact on CO2 emissions in Kazakhstan and emphasizes the importance of adopting sustainable policies and practices to mitigate environmental impacts while promoting economic development (Hasanove et al., 2019).

Furthermore, in a 2017 study conducted on 31 developing countries, the effect of economic growth on CO2 emissions was examined. Using a dynamic panel threshold framework, the researchers found a significant relationship between growth and CO2 emissions. Interestingly, economic growth was found to have a negative impact on CO2 emissions in the low growth regime but a positive impact in the high growth regime. The study also highlighted the importance of transitioning from non-renewable to renewable energy sources in order to achieve sustainable economic growth without increasing emissions (Goodness et al., 2017). Further research has supported the notion that the implementation of renewable energy mechanisms has led to a reduction in CO2 emissions. However, there are divergent views regarding the compatibility of CO2 emission reduction with economic growth (Cosmas et al., 2019).

Overall, the literature review reveals two key points. Firstly, economic growth has the potential to reduce climate vulnerability and increase resilience to disasters as income levels rise.

Secondly, there is a clear association between wealth and CO_2 emissions, indicating that higher levels of wealth are correlated with increased CO_2 emissions. Notably, the focus on EU countries in the existing literature is limited, which serves as the motivation for this study, aiming to investigate the relationship between real GDP and CO_2 emissions across EU countries in the context of climate change.

On the other hand, some studies suggest that there is a modifier inverted U-shaped relationship between economic development (measured by GDP per capita) and environmental sustainability (Tenaw et al. 2021).

In least developed countries

Least developed countries (LDCs) share common characteristics such as low income, limited human assets, and high economic vulnerability. These countries often heavily rely on natural resources, making them especially susceptible to the impacts of climate change. Consequently, exploring the relationship between CO_2 emissions per capita and GDP per capita in LDCs is crucial for understanding the opportunities and challenges associated with sustainable development in these nations.

Research investigating the connection between CO_2 emissions per capita and GDP per capita in LDCs has produced mixed findings. Some studies have identified a positive relationship between these variables, indicating that economic growth in LDCs is associated with increased carbon emissions. Vona and Patriarca (2011) found a positive correlation between CO_2 emissions per capita and GDP per capita in a sample of LDCs, suggesting that economic growth may contribute to higher carbon emissions in these countries.

Conversely, other studies have found a negative relationship between CO_2 emissions per capita and GDP per capita in LDCs, suggesting that economic growth may be accompanied by a reduction in carbon emissions. For example, Kivyiro and Arminen (2014) observed a negative relationship between these variables in a sample of Sub-Saharan African LDCs, implying that economic growth could be decoupled from increasing carbon emissions in these countries.

The varying outcomes of studies examining the relationship between CO_2 emissions per capita and GDP per capita in LDCs can be attributed, in part, to the heterogeneity among these countries. Factors such as geography, natural resources, level of economic development, and institutional frameworks differ significantly across LDCs, influencing the extent to which economic growth is linked to higher or lower carbon emissions. Additionally, many LDCs heavily depend on international aid, which can exert external pressures affecting their economic and environmental policies.

Methodological differences across studies also contribute to the divergent findings. Some studies utilize cross-sectional data, which may not capture the dynamic nature of the relationship between economic growth and carbon emissions over time. Furthermore, variations in measures of economic growth and environmental degradation employed in different studies can influence the results obtained.

Empirical Part

The objective of the empirical part is organized as follow: a presentation of the methodology, data used, the analysis and finally the results of our analysis. The aim is to provide an answer to the research question: "*How different is the relationship between CO2 per capita and GDP per capita in developed, developing and least developed countries?*".

Methodology

This study's theoretical framework, the Environmental Kuznets Curve (EKC) model proposed by Grossman and Krueger (1991), follows a similar analogy to Kuznets' original Kuznets curve (1955). Environmental pollution is thought to increase with economic growth up to a certain income threshold and decline with further increases in economic growth after this income threshold, according to the Environmental Kuznets Curve (EKC), a hypothesised relationship between various measures of environmental quality and economic growth. The typical EKC assumes that there is no environmental influence on the economy. Therefore, the EKC for carbon dioxide emissions postulates an inverse "U"-shaped relationship between economic growth and carbon dioxide emissions in its standard form. This may be illustrated as:

$$CO_{2t} = \beta_0 + \beta_1 GDP_t + \beta_2 GDP_t^2 + \delta X + \epsilon_t \qquad (1)$$

where CO_2 is carbon dioxide emissions per capita, GDP represents gross domestic product per capita, and X is a vector of macroeconomic control variables. The square of GDP is added to the model for the non-linearity in the relationship between economic growth and carbon dioxide emissions. For the inverted "U"-shaped relationship to exist, the EKC theory requires that $\beta_1 >$ 0 and $\beta_2 > 0$.

This paper examines the causal relationship between GDP per capita and CO_2 per capita using the vector autoregressive (VAR) framework. The Granger causality test begins by modelling a vector autoregressive (VAR) process between the two variables, namely the CO_2 per capita and the GDP per capita. The VAR (p) process is constructed as follows:

$$X_t = \theta_0 + \theta_1 X_{t-1} + \cdots . + \theta_p X_{t-p} + \epsilon_t t \qquad (2)$$

where the optimal lag order p is determined by the smallest value of Akaike information criterion (AIC). In the VAR (p) process in Eq. (2) above, X is a vector denoting carbon dioxide emission per capita (CO_2) and real gross domestic product per capita (GDP), i.e., $X_t = (CO_{2t}, GDP_t)'$. Then, we can rewrite the Eq (2) as follow:

$$\begin{bmatrix} CO_{2t} \\ GDP_t \end{bmatrix} = \begin{bmatrix} \theta_{10} \\ \theta_{20} \end{bmatrix} + \begin{bmatrix} \theta_{11}(L) & \theta_{12}(L) \\ \theta_{21}(L) & \theta_{22}(L) \end{bmatrix} \begin{bmatrix} CO_{2t\text{-}1} \\ GDP_{t\text{-}1} \end{bmatrix} + \begin{bmatrix} \epsilon_{1t} \\ \epsilon_{2t} \end{bmatrix} \quad (3)$$

where $\epsilon_t = (\epsilon_{1t}, \epsilon_{2t})'$ is a white noise process with zero mean and covariance matrix.

Data

Geography and Timeframe

To provide an answer to the research question, the geographical focus has been put on 6 different countries, namely: Sweden, USA, Brazil, India, Burkina Faso, and Haiti. Those countries have been chosen for various reasons:

1. Developed countries: ***The United States*** is known for its size, economic situation development but also its industrialization history. ***Sweden*** has been selected for its long history of sustainable development and environmental protection but also for its strong economy and level of living.
2. Developing countries: ***India*** is today according to the United Nations the most populous country in the world and faces a fast-growing economy and development. However, that rapid growth doesn't come without environmental consequences. ***Brazil*** is known for its biodiversity and natural resources. It is also a fast-growing economy that Is facing environmental issues such as deforestation.
3. Least developed countries: ***Burkina Faso*** and ***Haiti*** are classified by the United Nations[3] as least developed countries. They both have a fragile economy and a low standard or living.

All in all, the common reason for this choice of countries is the availability of data especially for least developed countries and developing country. Regarding the timeframe, it is also for reasons of data availability that annual data from 1960 to 2021 are used.

[3] https://unctad.org/topic/least-developed-countries/list

Variables

The main variables that are used in this paper are the **GDP per capita** as a measure of economic growth and the $\boldsymbol{CO_2}$ **emissions per capita** as a measure of the carbon footprint. The data were extracted from the database "Our World in Data" for the CO_2 emissions per capita which has been built. The source for the annual CO_2 emissions data is the Global Carbon Project and the population data used in this calculation combines three underlying data sources: the HYDE database (History database of the Global Environment); Gapminder; and the UN World Population Prospects. Regarding the GDP per capita, it has been extracted from the database "the World bank". This work is therefore based on a total of ***61 observations.***

Analysis

Developed countries

The Figure 1 shows that the GDP per capita has increased since 1960 until 2021 in the USA and in Sweden with a more linear growth for the USA as demonstrated by the graphic. while the CO_2 emissions per capita has fluctuated since 1960 with a peak in 1972 and a decrease since 2005 to reach its lowest value of all time in 2020. The Figure shows a similar trend when it comes to CO_2 emission per capita. Although the variable seems to be higher in the USA than in Sweden. We can observe a slight decrease over time for both countries.

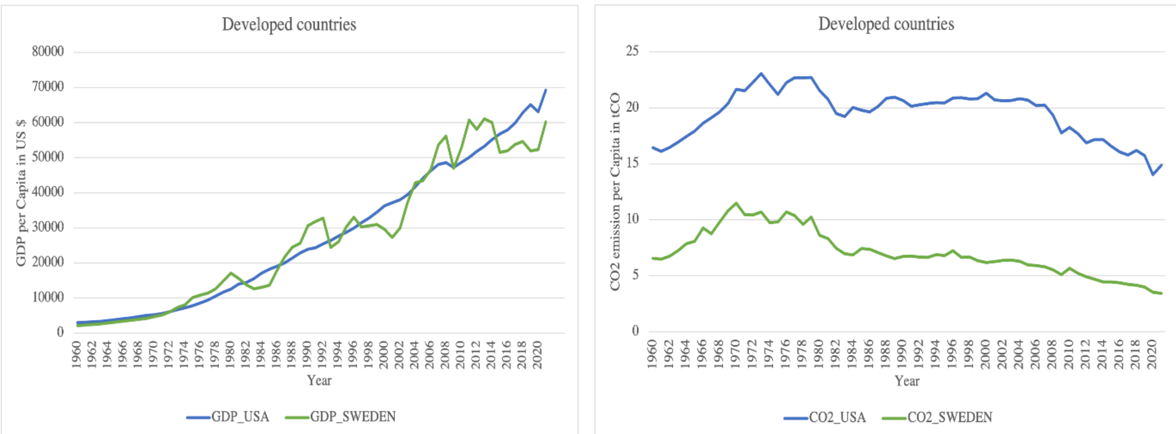

Figure 1: GDP per Capita and CO2 per capita in USA and Sweden (1960-2021)

The Figure 2 shows that whether it is for Sweden or USA, the highest the GDP per capita, the lowest is the CO2 emissions per capita. We can observe an inverted U-curve such as the EKC theory suggests. In fact, for a low GDP per capita, the CO2 emissions per capita is low and keeps increasing as GDP per capita increase until it reaches a certain point and start to decrease.

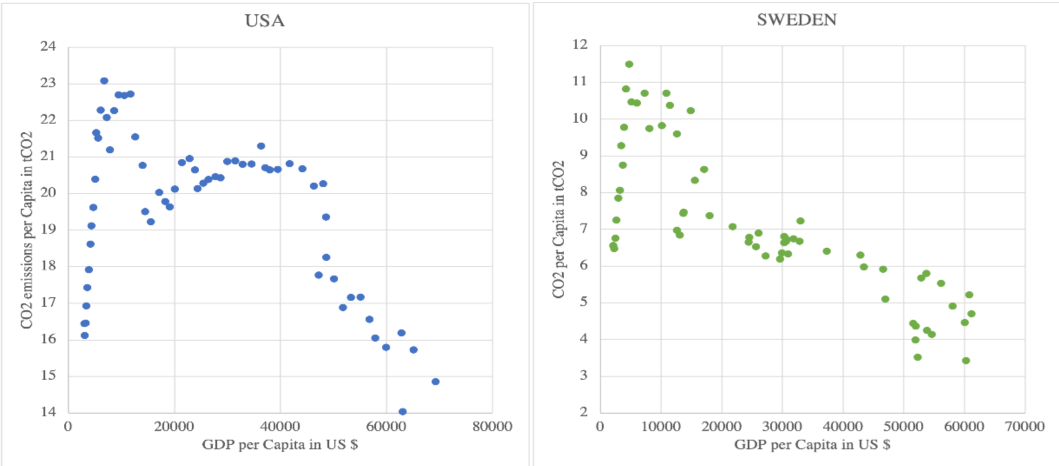

Figure 2: Link between CO2 per capita and GDP per capita in USA and Sweden

Developing countries

The Figure 3 shows an increase in the GDP per capita in Brazil with a peak in 2011 and as from then the GDP per capita started to fall. In India, a similar trend is observed with a peak in GDP per capita in 2019. Regarding the CO_2 per capita, in Brazil we can see (Figure 7) a similar trend than the GDP per capita. In fact, it's increased since 1960 to reach its highest value in 2014. While in 2011, that variable also was at one if its highest value. A similar trend of growth throughout the years is observed in India.

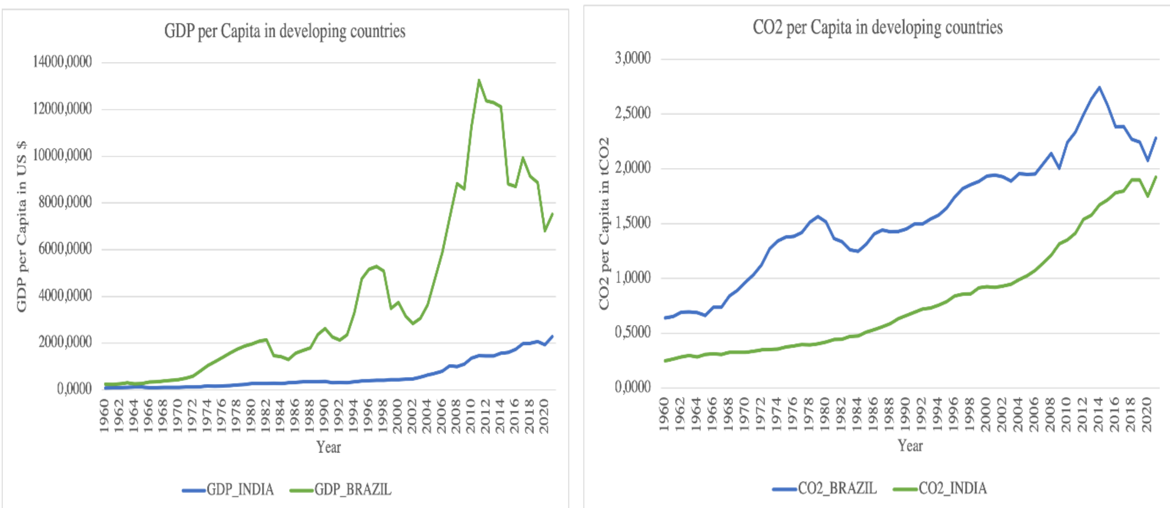

Figure 3. GDP per Capita and CO2 per capita in USA and Sweden (1960-2021)

To visualize the relation between the two variables better, just like in Brazil, we can affirm that it exists a strong linearity between the GDP per capita and the CO_2 per capita in India (***Figure 4***). The EKC theory doesn't hold in this case as the highest the GDP per capita, the highest the CO2 emissions per capita.

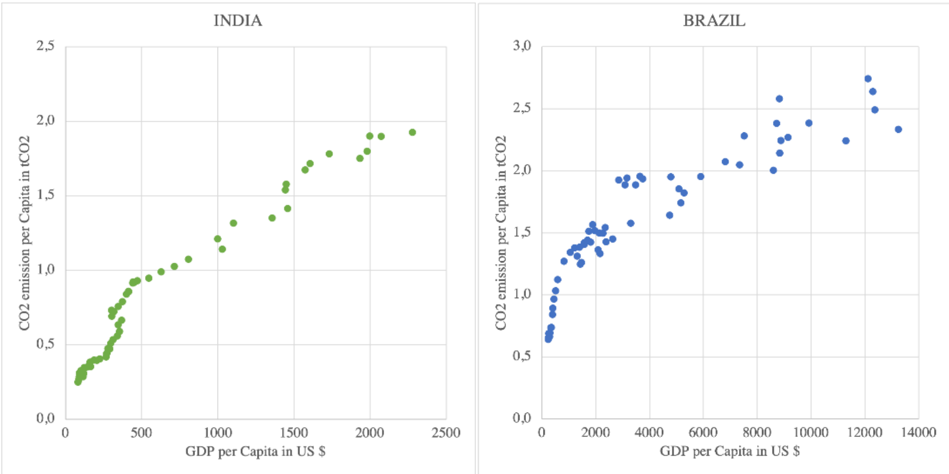

Figure 4: Link between CO2 per capita and GDP per capita in India and Brazil

Least developed countries

The Figure 5 shows a general increase in the GDP per capita in Burkina Faso and Haiti. Therefore, achieving, both variables their highest value in 2021 and their lowest value in 1960. Regarding the CO2 per capita, we can observe a general increase in tCO2 emissions since 1960 in Haiti and Burkina Faso. A drop in emissions can be seen on the figure for Haiti and this is mainly due to the political situation of the country at that time.

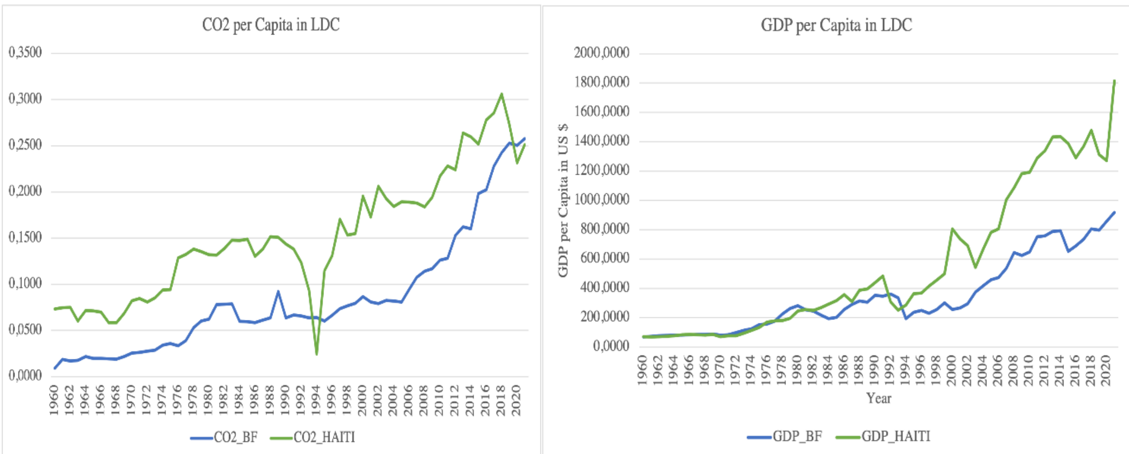

Figure 5: GDP per Capita and CO2 per capita in Haiti and Burkina Faso (1960-202)

The Figure 6 demonstrates that there is a positive linear relationship between the two variables. The highest the GDP per capita, the highest the CO2 emissions per capita and vice versa. Therefore, we can affirm that the EKC theory doesn't hold Burkina Faso and India.

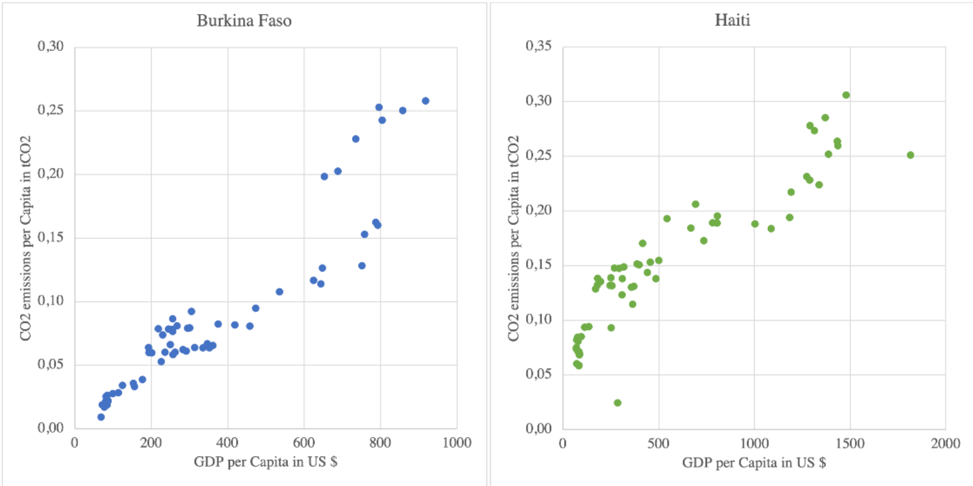

Figure 6*: *Link between CO2 per capita and GDP per capita in Burkina Faso and India

General observations

In general, following the observation of the two variables in different type of countries:

- The CO2 emissions per capita: In developed countries, the CO2 per capita tend to decrease over time since 1960. On the contrary, we see a rise in developing and under-developed countries.
- The GDP per capita: The GDP per capita seem to increase since 1960 whether we are facing developed, developing, or underdeveloped countries.

Results

This section will present the different test and results of our analysis to reach the conclusion.

Stationarity test

Stationarity is critical to development of a VAR model. In its absence, a model's statistics such as means and correlations will not accurately describe the time series signal. In this matter, the Augmented Dickey-Fuller test is used to test stationarity with the following:

- H0: The time series is non-stationary.
- HA: The time series is stationary.

Rejection of the null hypothesis indicates that the series does not need transformation to achieve stationarity and modelling can proceed to the lag length selection step.

Developed countries

Table 1 demonstrates that in the USA and in Sweden, the GDP and CO2 per capita are both trend stationary when using the first difference time series. Therefore, they reject the unit root process at the 5% significance level meaning they are stationary. As to build the VAR model, the first difference time series of the GDP per Capita and CO2 per Capita will be used for the USA and Sweden.

Variable	Type	t-stat	1pct	5pct	10pct
LGDP	None	6.44	-2.6	-1.95	-1.61
LGDP	Drift	4.32	-3.51	-2.89	-2.58
LGDP	Trend	-1.69	-4.04	-3.45	-3.15
Diff(GDP,1)	None	-1.10	-2.6	-1.95	-1.61
Diff(GDP,1)	Drift	-2.85	-3.51	-2.89	-2.58
Diff(GDP,1)	Trend	-4.22	-4.04	-3.45	-3.15
LCO2	None	-0.27	-2.6	-1.95	-1.61
LCO2	Drift	-1.18	-3.51	-2.89	-2.58
LCO2	Trend	-2.18	-4.04	-3.45	-3.15
Diff(CO2,1)	None	-5.25	-2.6	-1.95	-1.61
Diff(CO2,1)	Drift	-5.23	-3.51	-2.89	-2.58
Diff(CO2,1)	Trend	-6.53	-4.04	-3.45	-3.15

Variable	Type	t-stat	1pct	5pct	10pct
LGDP	None	1.43	-2.6	-1.95	-1.61
LGDP	Drift	-0.27	-3.51	-2.89	-2.58
LGDP	Trend	-3.30	-4.04	-3.45	-3.15
Diff(GDP, 1)	None	-4.33	-2.6	-1.95	-1.61
Diff(GDP,1)	Drift	-5.29	-3.51	-2.89	-2.58
Diff(GDP,1)	Trend	-5.73	-4.04	-3.45	-3.15
LCO2	None	-0.77	-2.6	-1.95	-1.61
LCO2	Drift	-0.11	-3.51	-2.89	-2.58
LCO2	Trend	-3.34	-4.04	-3.45	-3.15
Diff(CO2,1)	None	-4.00	-2.6	-1.95	-1.61
Diff(CO2,1)	Drift	-4.24	-3.51	-2.89	-2.58
Diff(CO2,1)	Trend	-4.95	-4.04	-3.45	-3.15

Table 1: Stationarity test results: USA (left) and Sweden (right)

Developing countries

Table 2 demonstrates same type of results as for the developed countries. In fact, the GDP and CO2 are both trend stationary when using the 1st difference time series. We then reject the unit root process at the 5% significance level meaning they are stationary. We will also use the first-time difference time series of the GDP and CO2 per capita when building the VAR for Brazil and India.

Variable	Type	t-stat	1pct	5pct	10pct
LGDP	None	5.31	-2.6	-1.95	-1.61
LGDP	Drift	3.84	-3.51	-2.89	-2.58
LGDP	Trend	0.85	-4.04	-3.45	-3.15
Diff(GDP,1)	None	-3.63	-2.6	-1.95	-1.61
Diff(GDP,1)	Drift	-5.11	-3.51	-2.89	-2.58
Diff(GDP,1)	Trend	-5.15	-4.04	-3.45	-3.15
LCO2	None	5.61	-2.6	-1.95	-1.61
LCO2	Drift	3.04	-3.51	-2.89	-2.58
LCO2	Trend	-0.74	-4.04	-3.45	-3.15
Diff(CO2,1)	None	-2.72	-2.6	-1.95	-1.61
Diff(CO2,1)	Drift	-5.63	-3.51	-2.89	-2.58
Diff(CO2,1)	Trend	-5.72	-4.04	-3.45	-3.15

Variable	Type	t-stat	1pct	5pct	10pct
LGDP	None	-0.13	-2.6	-1.95	-1.61
LGDP	Drift	-1.11	-3.51	-2.89	-2.58
LGDP	Trend	-2.36	-4.04	-3.45	-3.15
Diff(GDP,1)	None	-3.88	-2.6	-1.95	-1.61
Diff(GDP,1)	Drift	-4.10	-3.51	-2.89	-2.58
Diff(GDP,1)	Trend	-4.26	-4.04	-3.45	-3.15
LCO2	None	1.42	-2.6	-1.95	-1.61
LCO2	Drift	-1.20	-3.51	-2.89	-2.58
LCO2	Trend	-2.63	-4.04	-3.45	-3.15
Diff(CO2,1)	None	-3.18	-2.6	-1.95	-1.61
Diff(CO2,1)	Drift	-3.55	-3.51	-2.89	-2.58
Diff(CO2,1)	Trend	-3.68	-4.04	-3.45	-3.15

Table 2: Stationarity test results: India (left) and Brazil (right)

Least developed countries

As for under-developed countries, as outlined in the ***Table 3*** below, we will also use the first-time difference time series of the GDP per capita and the CO2 per capita when building the VAR model for Burkina Faso and Haiti.

Variable	Type	t-stat	1pct	5pct	10pct
LGDP	None	2.25	-2.6	-1.95	-1.61
LGDP	Drift	0.78	-3.51	-2.89	-2.58
LGDP	Trend	-1.37	-4.04	-3.45	-3.15
Diff(GDP,1)	None	-5.01	-2.6	-1.95	-1.61
Diff(GDP,1)	Drift	-5.37	-3.51	-2.89	-2.58
Diff(GDP,1)	Trend	-5.32	-4.04	-3.45	-3.15
LCO2	None	4.26	-2.6	-1.95	-1.61
LCO2	Drift	2.74	-3.51	-2.89	-2.58
LCO2	Trend	0.55	-4.04	-3.45	-3.15
Diff(CO2,1)	None	-4.96	-2.6	-1.95	-1.61
Diff(CO2,1)	Drift	-5.77	-3.51	-2.89	-2.58
Diff(CO2,1)	Trend	-5.72	-4.04	-3.45	-3.15

Variable	Type	t-stat	1pct	5pct	10pct
LGDP	None	2.39	-2.6	-1.95	-1.61
LGDP	Drift	1.11	-3.51	-2.89	-2.58
LGDP	Trend	-1.40	-4.04	-3.45	-3.15
Diff(GDP, 1)	None	-4.96	-2.6	-1.95	-1.61
Diff(GDP,1)	Drift	-5.58	-3.51	-2.89	-2.58
Diff(GDP,1)	Trend	-5.53	-4.04	-3.45	-3.15
LCO2	None	0.69	-2.6	-1.95	-1.61
LCO2	Drift	-0.93	-3.51	-2.89	-2.58
LCO2	Trend	-2.89	-4.04	-3.45	-3.15
Diff(CO2,1)	None	-5.84	-2.6	-1.95	-1.61
Diff(CO2,1)	Drift	-5.83	-3.51	-2.89	-2.58
Diff(CO2,1)	Trend	-5.78	-4.04	-3.45	-3.15

Table 3: Stationarity test results: Burkina Faso (left) and Haiti (right)

Co-integration test

To test the cointegration, the Johansen procedure is used. After running the test, we get the result in the ***Table 4*** below. This table tells us that when r is equal to 0, the test statistic is bigger than the 5% critical value meaning that we reject the null hypothesis and when r <= 1, the test statistic is smaller than the 5% critical value, meaning that we fail to reject the null hypothesis for the first time when r<=1. Therefore, we have cointegration relationships.

		test	10pct	5pct	1pct
USA	r<=1	8.5	10.49	12.25	16.26
	r=0	45.18	16.85	18.96	23.65
Sweden	r<=1	20.17	10.49	12.25	16.26
	r=0	29.04	16.85	18.96	23.65
India	r<=1	18.49	10.49	12.25	16.26
	r=0	32.27	16.85	18.96	23.65
Brazil	r<=1	12.92	10.49	12.25	16.26
	r=0	17.29	16.85	18.96	23.65
Burkina Faso	r<=1	22.65	10.49	12.25	16.26
	r=0	34.92	16.85	18.96	23.65
Haiti	r<=1	19.59	10.49	12.25	16.26
	r=0	63.95	16.85	18.96	23.65

Table 4: Co-integration Test results

VAR Model

This section presents the various equations that will be used for the Granger Causality test.

For reference, US: USA; SWE: Sweden; IN: India; BRA: Brazil; BF: Burkina Faso; HA: Haiti.

Developed countries

$$CO2US_t = 0.090 - 0.0016_t - 0.46GDPUS_{t-1} + 0.05CO2US_{t-1} - 0.35GDPUS_{t-2} - 0.19CO2US_{t-2}$$

$$CO2SWE_t = 0.039 - 0.00149_t - 0.113GDPSWE_{t-1} - 0.068CO2SWE_{t-1}$$

$$GDPUS_t = 0.06 - 0.0008_t + 0.19GDPUS_{t-1} - 0.13CO2US_{t-1} + 0.14GDPUS_{t-2} - 0.15CO2US_{t-2}$$

$$GDPSWE_t = 0.0721914 - 0.00097_t + 0.19GDPSWE_{t-1} + 0.236CO2SWE_{t-1}$$

Developing countries

$$CO2IN_t = 0.0302823 + 0.0001395_t + 0.0382820GDPIN_{t-1} - 0.1400180CO2IN_{t-1}$$

$$GDPIN_t = 0.0492548 - 0.0005106_t + 0.0237832GDPIN_{t-1} - 0.5302740CO2IN_{t-1}$$

$$CO2BRA_t = 0.0310951 - 0.0005083_t + 0.0149290GDPBRA_{t-1} + 0.2044086CO2BRA_{t-1}$$

$$GDPBRA_t = 0.083940 - 0.001547_t + 0.264495GDPBRA_{t-1} - 0.137898CO2BRA_{t-1}$$

Least developed countries

$$CO2BF_t = 0.0246440 + 0.0003152_t + 0.2410730GDPBF_{t-1} - 0.1415432CO2BF_{t-1}$$

$$GDPBF_t = (2.515e - 02) - (5.431e - 05)_t + (7.641e - 02)GDPBF_{t-1} + (1.760e - 01)CO2BF_{t-1}$$

$$CO2HA_t = -0.14 + 0.0005_t + 0.74GDPHA_{t-1} - 0.35CO2HA_{t-1} + 1.7GDPHA_{t-2} - 0.061CO2HA_{t-2}$$

$$GDPHA_t = 0.045 - 0.0001_t + 0.13GDPHA_{t-1} - 0.053CO2HA_{t-1} - 0.087GDPHA_{t-2} + 0.01CO2HA_{t-2}$$

Test Autocorrelation

The assumption is that the residuals should not be autocorrelated. Again, this assumes that the residuals are white noise and therefore uncorrelated with previous time periods. As the autocorrelation is an undesirable feature of a model and the results tell us that:

- For the **USA**, the null hypothesis of no autocorrelation cannot be rejected since the p-value of 0.7477 is higher than the significance level of 0.05. So, the residuals show no sign of autocorrelation.

- For **Sweden**, the null hypothesis of no autocorrelation cannot be rejected since the p-value of 0.5635 is higher than the significance level of 0.05. So, the residuals show no sign of autocorrelation.
- For **Brazil**, the null hypothesis of no autocorrelation cannot be rejected since the p-value of 0.629 is higher than the significance level of 0.05. So, the residuals show no sign of autocorrelation.
- For **India**, the null hypothesis of no autocorrelation cannot be rejected since the p-value of 0.84 is higher than the significance level of 0.05. So, the residuals show no sign of autocorrelation.
- For **Burkina Faso**, the null hypothesis of no autocorrelation cannot be rejected since the p-value of 0.4761 is higher than the significance level of 0.05. So, the residuals show no sign of autocorrelation.
- For **Haiti**, the null hypothesis of no autocorrelation cannot be rejected since the p-value of 0.3823 is higher than the significance level of 0.05. So, the residuals show no sign of autocorrelation.

Engle's ARCH test

Another aspect to consider is the presence of heteroscedasticity. Time series have the so-called ARCH effect, which is essentially a clustered area of volatility in the time series. This is common in series like stocks that see significant gains or losses when earnings reports are released. Excessive volatility can occur in this range or window, causing the residual variance to deviate significantly from the constant variance assumption. The results shows that there are no ARCH effects.

Testing the Normality

A soft but desirable assumption is the normality of the distribution of the residuals. This introduces the Jarque-Bera, Kurtosis and Skewness tests. Based on all three results, the residuals for this model do not appear to be normally distributed. The residuals are not normally distributed because the p-value is indeed lower than the significance level of 0.05 for the USA, India, Sweden, Brazil, Burkina Faso, and Sweden.

Stability test

A stability test is a test for the presence or absence of structural failure. We know that we can't test for structural damage and if damage does occur, the entire quote may be scrapped. Fortunately, there is a simple test that uses a plot of the recursive sum of residuals. If the sum of any point on the graph exceeds the red limit value, structural failure is visible at that point. Our analysis show that there are no structural breaks evident in the USA, Sweden, India, Brazil, Burkina Faso, and Haiti (Appendix 1)

Granger Causality Test

The Granger Causality test is used to examine if one time series may be used to forecast another. Here we want to study the possible link between the two variables. We want to know if the CO2 per Capita causes the GDP per Capita and inversely.

	GDP per capita fail to Granger Cause the CO2 per capita	**CO2 per capita fail to Granger Cause the GDP per capita**
	p-value	**p-value**
USA	0.0022010	0.1352000
Sweden	0.1597000	0.2845000
India	0.4335000	0.1539000
Brazil	0.7311000	0.7807000
Burkina Faso	0.0238600	0.2073000
Haiti	0.0000001	0.5388000

The following conclusion can be drawn from the above results, considering a 5% level:

- **USA:**
  - We can reject the null hypothesis. That is, the GDP per capita Granger cause the CO2 per capita in USA.
  - We can’t reject the null hypothesis. That is, the CO2 per capita doesn't Granger cause the GDP per capita in USA.
- **Sweden**
  - We can’t reject the null hypothesis. That is, the GDP per capita doesn't Granger cause the CO2 per capita in Sweden.
  - We can’t reject the null hypothesis. That is, the CO2 per capita doesn't Granger cause the GDP per capita in Sweden.
- **India**

- We can’t reject the null hypothesis. That is, the GDP per capita doesn't Granger cause the CO_2 per capita in India.
- We can’t reject the null hypothesis. That is, the CO_2 per capita doesn't Granger cause the GDP per capita in India.

- **Brazil**
  - We can’t reject the null hypothesis. That is, the GDP per capita doesn't Granger cause the CO_2 per capita in Brazil.
  - We can’t reject the null hypothesis. That is, the CO_2 per capita doesn't Granger cause the GDP per capita in Brazil.
- **Burkina Faso**
  - We can reject the null hypothesis. That is, the GDP per capita Granger cause the CO_2 per capita in Burkina Faso.
  - We can’t reject the null hypothesis. That is, the CO_2 per capita doesn't Granger cause the GDP per capita in Burkina Faso.
- **Haiti**
  - We can reject the null hypothesis. That is, the GDP per capita Granger cause the CO_2 per capita in Haiti.
  - We can’t reject the null hypothesis. That is, the CO_2 per capita doesn't Granger cause the GDP per capita in Haiti.

To summarize, the above results demonstrate that whether we are in a developed, developing and least developed country, the CO_2 emissions per capita doesn’t Granger cause the GDP per capita. However, when looking at the USA, Burkina Faso, and Haiti, we can see clearly that the GDP per capita Granger cause the CO_2 per capita.

Further analysis and results

As to assess the validity of the analysis and to widen the scope of study. Three additional binary variables have been added to the equation to assess their causality on the main variable. Mainly the following variables:

- The Banking Crisis (BC)
- The Currency Crisis (CC)

- The Exchange Rate (XR)

The results of the analysis show that:

- Developed countries: For **Sweden**, only the exchange rate variable is significant on the GDP per capita and CO2 emissions per capita. However, the results also show that the Banking crisis also have its significance on the GDP per capita. As for the **USA**, the Banking crisis and the currency crisis are both significant on the GDP per capita but no exogenous variable have an impact on the CO2 emissions per capita.
- Developing countries: For **Brazil**, the exogenous variables seem to have no incidence on CO2 emissions per capita nor the GDP per capita. However, the GDP per capita seems to be significant on the CO2 emissions per capita and vice versa. And regarding **India**, only the exchange rate seems to be highly significant on the GDP per Capita variable while no exogenous variable impact on the CO2 emissions per capita.
- Least developed countries: For **Haiti**, the exchange rate is significant on the GDP per capita variable while the banking crisis is highly significant on the CO2 emissions per capita variable. As for **Burkina Faso**, the three exogenous variables show a high significance on GDP per capita variable and as for the CO2 per capita, the banking crisis and exchange rate seem to be slightly significant on the variable.

By adding binary additional variables, we can see that in general, CO2 emissions per capita and GDP per capita are still not significant on each other. However, this test can be done with additional variables to see the impact on CO2 and GDP per capita.

Conclusion

This comprehensive comparative analysis of studies investigating the relationship between CO2 emissions per capita and GDP per capita across different types of countries from 1960 to 2021 provides valuable insights into the intricate nature of this relationship. The findings highlight that the link between CO2 emissions and GDP per capita is not straightforward; instead, it exhibits complexities influenced by various factors such as the structure of the economy and availability of natural resources.

For developed countries, in this case, Sweden and USA, the analysis reveals graphical evidence of an inverted U-shaped relationship between CO2 emissions and GDP per capita, aligning with the Environmental Kuznets Curve (EKC) hypothesis. Although the curve is more visible in the USA. The Granger causality test shows that for the USA, the GDP per capita Granger cause the CO2 emissions per capita but not inversely. Moreover, when it comes to Sweden, it seems that none of the variable Granger cause the other. Meaning, although from a graphical perspective the EKC theory seems to hold for the two developed countries, the statistical hypothesis test to determine whether the variable is useful to forecast the other doesn't hold.

Contrarily, the relationship between CO2 emissions and GDP per capita in developing countries, appears to be less definitive. While certain studies have identified an inverted U-shaped relationship, indicating that economic growth is associated with an initial increase followed by a decrease in carbon emissions, this analysis, focusing on India and Brazil, uncovers a positive linear relationship. This suggests that economic growth in these contexts is accompanied by an increase in carbon emissions. One plausible explanation for this discrepancy lies in the fact that developing countries are still in the process of industrialization and heavily rely on energy-intensive industries. Although the Granger Causality test affirms that none of the variable Granger cause the other whether it is the CO2 emissions per capita or GDP per capita.

Finally, least developed countries present an additional layer of complexity in the relationship between CO2 emissions and GDP per capita. While this analysis discovers evidence of a positive linear relationship in these countries, other studies have found no significant relationship at all. This disparity may arise from the predominantly agrarian nature of these countries, their lower levels of industrialization, and relatively modest energy consumption patterns. However, the Granger causality test affirms that only the GDP per capita Granger cause the CO2 per capita for both Burkina Faso and Haiti.

Taken together, this comparative analysis emphasizes that the relationship between CO2 emissions and GDP per capita is multifaceted and varies across different types of countries. Further research is needed to gain a deeper understanding of the influencing factors and to identify effective policies for mitigating carbon emissions.

Limits

Data availability and quality present a major obstacle. Many developing and least developed countries lack reliable data on CO2 emissions and GDP per capita, making it difficult to accurately estimate the relationship between these variables. The selection of control variables is another challenge. Determinants of CO2 emissions and GDP per capita differ between developing and developed countries, necessitating careful selection of control variables to avoid misleading results. This study has ben focused on 6 countries from different types of countries using time-series data and one econometric theory. This opens the door to further studies that can explore other countries using panel data and other econometric theories.

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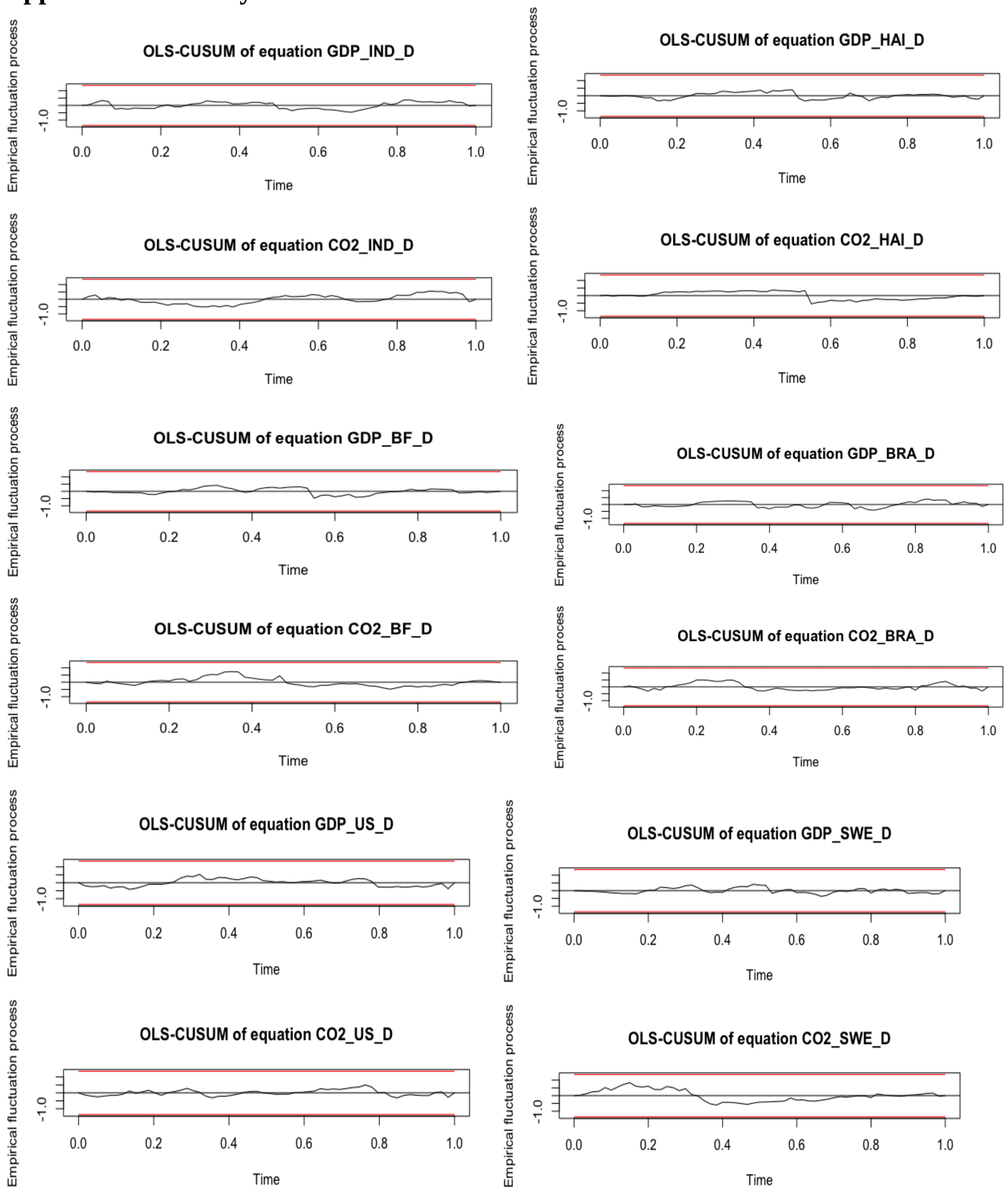
Appendix

Appendix 1: Stability Test Results



Abstract:

The aim of this paper is to assess the validity of the Environmental Kuznets Curve (EKC) in developed, developing and least developed countries (LDC) over a selected period, 1960-2021. The EKC suggests that environmental degradation grows with economic development, but that this increase has a limit and that once reached, it will start to decrease. This trend has been seen in many developed or industrialized countries however it is less certain in developing and least developed countries. Using a VAR model and the Granger Causality test, the result of this study demonstrates how complex and uncertain the relationship between CO2 emissions per capita and GDP per capita is. Considering the six countries selected, although the EKC holds for developed countries, the study demonstrates a linear relationship between the variables CO2 emissions per capita and GDP per capita in developing and least developed countries. Nevertheless, the results of the Granger Causality test show that neither variable causes the other, except in the case of the USA.

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