INVESTIGATING THE RELATIONSHIP BETWEEN GDP AND CO_2 EMISSIONS ON A CROSS-NATIONAL SCALE

by

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I. INTRODUCTION

Since the dawn of the Anthropocene, climate change has continuously grown as a threat to the biosphere as we know it. Per Li (2020:289), “the Anthropocene refers to the Earth's most recent geologic period in which geochemical, biological, atmospheric, and other earth system processes have been transformed by significant human impact.” The Anthropocene has been characterized by the consistent acceleration of climate change and degradation towards the natural world. While some of these shifts in climate occur naturally, the main driver of climate change, according to the consensus among the vast majority of the world's scientific community, can be attributed to human activity. Human activity encompasses a wide range of processes and actions, but our activity's main contribution to changes in climate can be attributed to the burning of fossil fuels such as coal, gas, and oil. Since the Industrial Revolution, humans have continuously burned fossil fuels to drive the exponential growth of world economies through innovations in mobility, electricity generation, and the like. Yet, this volume of growth through fossil fuel burning thrusts huge volumes of greenhouse gas emissions, or GHGs, into the atmosphere causing a greenhouse effect resulting in the continuous warming of the globe and environmental degradation in general. Li (2020:289) notes that “although significant human impact began about eight thousand years ago when agricultural civilizations emerged, massive and fundamentally unsustainable human impact has taken place only during the modern capitalist era.” These impacts have become clearer as industrialization has progressed.

Some examples include:

- Increased erosion now exceeds natural sediment production by an order of magnitude.
- Carbon dioxide and methane levels are significantly higher than at any time in nearly a million years and are rising much faster than in any previous warming period.
- Mass extinctions, species migrations, and replacement of natural vegetation with agriculture monocultures are changing the nature of the biosphere.
- Sea level rise may reach ten to thirty meters for each 1°C increase in temperature, and acidification of ocean water will have severe effects on coral reefs and plankton. (Angus 2016:50)

Out of these examples, rising greenhouse gas emissions have become one of the most crucial focus points concerning human-driven environmental impacts. According to the US EPA (2015), four main greenhouse gases contribute to global warming and climate change: carbon dioxide, methane, nitrous oxide, and fluorinated gases with carbon dioxide being the primary greenhouse gas that results from human activities. Because of this, the Earth is 1.1 degrees Celsius warmer on average compared to the beginning of the Industrial Revolution with the last decade being the warmest in recorded human history. According to Angus (2016:65), by 1945, CO_2 was 25 parts per million above the preindustrial level, in 2015 it was 120 ppm above. Considering the scope of degradation, this problem is not country-specific, rather it is a world issue that demands international cooperation to alleviate its most devastating effects. Unfortunately, based on current climate policies, global warming will likely warm the world by 2.7 degrees Celsius by the dawn of the next century. Such drastic changes in global temperatures will undoubtedly have dramatic effects on future generations as environmental degradation will surely create new and evolving forms of global risks that need to be attended to. In an effort to curb such effects, world organizations have begun to focus on sustainability as a means of approaching concerns of current and future environmental degradation and a warming globe.

The United Nation has set out, through various programs, to reduce such climate impacts and environmental degradation. Most notable is their Sustainability Development Goals (SDGs), comprised of 17 goals spanning various sectors of consideration. Most concerning of the goals, and what this thesis aims to address, is SDG 8. SDG 8 aims to "promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all" (United Nations n.d.). While this goal includes relatively uncontroversial aims, such as its goal to provide decent work for all, its targets of economic growth are especially concerning. For example, Target 8.1 aims to "sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7 percent gross domestic product growth per annum in the least developed countries" (United Nations n.d.). The fact that the prime target of SDG 8 appears to be entirely based on a growth-centric maxim garners explicit concern from an eco-historical perspective. This is especially concerning considering economic growth's (GDP per capita) long-running relationship with greenhouse gas emissions and more specifically with, and what this thesis aims to use as a measure of environmental degradation, CO_2 emissions on a global scale.

According to Ritchie and Roser (2020), almost two-thirds of global energy comes from the burning of fossil fuels. This means that the majority of energy produced today still emits incredible amounts of CO_2 into the atmosphere. With continuous growth comes the need for more energy, thus resulting in more greenhouse gas emissions (particularly CO_2). Based on data from Ritchie and Roser (2020), it seems there is a positive relationship between GDP per capita and annual CO_2 emissions per capita globally. Li (2020:291) also states that "historically, world economic growth has been closely correlated with carbon dioxide emissions. From 1870 to 2018, gross world product grew from 1.9 trillion dollars to 121 trillion dollars or by 62.4 times; during the same period, world carbon dioxide emissions grew from about 540 million metric tons to 33.9 billion metric tons or by 62.9 times."

This thesis aims to address an important question: **Does economic growth (GDP), controlling for other variables empirically associated with growth, contribute to climate change (CO_2 emissions)?** While such a question has been examined in much of the literature (e.g., Lane 2011; Mitić et al. 2017), few studies (Sikder et al. 2022) have attempted to control for other variables empirically associated with growth in order to discover GDP's 'true effect' on CO_2 emissions. In order to answer this question, this thesis shall examine the correlation between GDP per capita and CO_2 per capita on a cross-national scale. Control variables up for consideration will include foreign direct investment, renewable energy consumption, an industry variable, and two urban variables. This will call into question the aims of the Sustainable Development Goals, specifically Goal 8, and how such economic growth targets may hinder sustainability achievement and drive additional forms of environmental degradation, especially in developing economies where there is a strong emphasis on growth.

II. LITERATURE REVIEW

Sustainability

The idea of sustainability has been around for quite a while but gained its immense popularity in 1987 when the United Nations Brundtland Commission defined it as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations n.d.). The United Nations acts as the main international agency concerned with sustainability, pushing for what it calls 'sustainable development' as an urgent priority. Sustainable development can be comprised of three distinct yet interconnected pillars. These are economic, social, and environmental pillars concerned with profit, people, and the planet respectively. In an effort to integrate these core considerations, the United Nations composed the Sustainable Development Goals or SDGs. First conceived as the Millennium Development Goals (MDGs) at the 1992 Earth Summit composed of only 8 goals aimed at primary reducing poverty and mortality, the SDGs took the goals further. At the UN Sustainable Development Summit in 2015, the United Nations adopted the 2030 Agenda for Sustainable Development with 17 distinct goals widening the scope of sustainability considerations. While the first and most important goal remains ending poverty, the SDGs include goals concerning health, education, gender equality, and energy, all through the lens of sustainability as the prime consideration in goal achievement.

While such goals may appear uncontroversial and beneficial to the general ideals of sustainable development, there are some considerations that need to be made. When discussing the goals of sustainability, there is a popular consideration for the ‘Three E’s”. These three include economy, equity, and ecology and are championed as a balancing act. In order to achieve a sustainable future, these three need to act in relation to one another in an effort to appease the different aspects of growth, the environment, and the notion of equality. Neglecting any ‘E’ results in a less holistic consideration of sustainability and can lead to negative effects. For example, Clement et al. (2020) examined the interconnectedness of the Three Es of sustainable development. The authors found that increased income inequality (less equity consideration) led to less renewable energy consumption (less environmental consideration) on a country-level between 1990 and 2015. Thus, less consideration of the certain parts of sustainable development leads to worse outcomes for the whole. Conversely, Clement et al. (2020:105) find that “greater equality results in more renewable energy consumption”. This demands a greater consideration of each of the Es in order to achieve the goals of a sustainable world. Current trends of global development focus on steady growth leading to an unequal consideration for the economy over equity and ecology. Thus, it is important to examine economic growth’s effect on climate change and consider its role in the achievement of sustainable development.

Economic Growth as GDP

Gross domestic product (GDP) was originally conceptualized by Simon Kuznets in 1934 and was subsequently adopted as the primary means of measuring a nation's economy at the Bretton Woods conference in 1944. Simply, the gross domestic product is “the market value of goods and services produced by a country in a certain time period” (O’Neill 2021). Kuznets himself suggested that GDP was one of the most important inventions of the modern era. This seems to hold true today as GDP is the primary measure of economic progress among economists and drives policymaking decisions within governments. Shrotryia and Singh (2020:144) write that it is undoubtedly the widest used statistical indicator in the world and is backed by various academics making it the most common measure for economic activity. GDP is used as a primary measurement tool to assess some key questions about world economics. According to Shrotryia and Singh (2020), GDP uncovers important metrics of the economy such as the rate that the economy is growing, what spending patterns appear, the ratio between spending and saving and what portion of growth is a result of inflation.

GDP can be measured in various ways. The two main ways are by measuring spending or measuring income. Income GDP includes a calculation of all of the “factors of production” that exist within an economy. This includes wages, rents, interests, and profits which eventually add up to make national income. Alternatively, spending GDP accounts for spending of all groups within the economy. In summation, according to Thangavelu (n.d.) “a country’s GDP is the total of consumer spending (C) plus business investment (I) and government spending (G), plus net exports, which is total exports minus total imports (X – M).” Each of these types of measurements yields what is referred to as nominal GDP. Once the effects of inflation are removed, nominal GDP becomes what economists refer to as “real GDP” which is the primary indicator of an economy's rate and state of growth.

It is important to note that while GDP is a measure of “economic progress”, it is typically conflated with well-being in general. Several academics suggest that GDP falls short of being a holistic measure of progress and well-being offering a similar critique of GDP’s “one-size-fits-all” approach to progress which typically is conflated with the overall welfare of a population. (e.g. Shrotryia and Singh 2020:148; Moulton 2018:335). Certainly, GDP cannot possibly measure all aspects of well-being as such a measure would have to account for a multitude of variables of which some lack appropriate data or simply cannot be quantified. Despite GDP’s shortfalls, this thesis aims to examine how economic growth affects or contributes to climate change. Thus, a measure of GDP is a reasonable, accessible, and rational method of attempting to measure economic growth even with its lack of consideration of extraneous variables related to well-being.

Climate Change as CO_2 Emissions

Finding a way to measure climate change proves to be difficult as there are a variety of factors that contribute to the various manifestations of climate change and global warming. It has been well established that greenhouse gas emissions (GHGs) are the primary contributors to such change and warming. According to the European Commission (n.d.), greenhouse gases are the primary cause of climate change as these gases contribute to the greenhouse effect. The greatest contributor to the greenhouse effect is undoubtedly carbon dioxide (CO_2). According to NASA (n.d.), CO_2 is a heat-trapping gas that emits as a result of various human activities such as the burning of fossil fuels. While other GHGs are also contributors to climate change, they seem to pale in comparison to CO_2's abundance.

Other GHGs, such as methane, may be more powerful than CO_2, but according to the European Commission (n.d.), have much lower atmospheric lifetimes. Other examples, such as nitrous oxide, act similarly to CO_2 but are emitted in much lower quantities. According to the Center for Climate and Energy Solutions (n.d.), CO_2 makes up about 76 percent of total greenhouse gas emissions, while methane makes up about 16 percent and nitrous oxide at about 6 percent respectively.

This thesis primarily focuses on climate change related to pollution, as pollution is the main driver of climate change which will subsequently affect other indicators related to natural resources extraction and other formations of environmental degradation. The most available indicator of climate change is CO_2 emissions. Considering CO_2 holds the highest share of GHG emissions globally, it makes sense to focus on CO_2 as a key indicator considering the availability of data for each country. Other GHGs do contribute to climate change, but most of the literature retrieved primarily uses CO_2 emissions as an indicator of climate change in relation to economic growth.

The GDP-CO_2 Nexus

The nexus between economic growth (GDP) and CO_2 emissions has been widely discussed throughout the literature. In an effort to examine the relationships between GDP and CO_2 emissions, the literature examines four different hypothesizes. Per Chaabouni and Saidi (2017):

(1) Unidirectional causality (growth and conservation hypothesis)
   a. The growth hypothesis suggests a unidirectional causality running from GDP to CO_2 emissions.
   b. The conservation hypothesis suggests a unidirectional causality running from CO_2 emissions to GDP.

(2) Bidirectional causality (feedback hypothesis) suggests a bidirectional relationship between CO_2 emissions and GDP.

(3) No causality (neutrality hypothesis) suggests no relationship between CO_2 emissions and GDP.

Following this, some studies examine the relationship between CO_2 emissions and GDP alone while others consider multiple variables such as population, foreign direct investment, and energy consumption along with GDP using multiple regression techniques. Xia et al. (2021:604) found that "among the 103 countries with increasing CO_2 emissions, 63 were driven primarily by income, 26 by population, nine by carbon intensity increase, and five by energy intensity increase." It seems that most countries with rising CO_2 emissions are seeing such increases as a result of increasing GDP and economic growth.

Literature on the Relationship Between GDP and CO_2 Emissions

The association between GDP and CO_2 emissions has been examined by a multitude of scholars. The consensus is not completely clear concerning a definite relationship as some studies are quite small in their scope and some countries included in the analysis are highly variable. In addition, as previously stated, some of the literature, while testing for a relationship between GDP and CO_2 emissions, also finds relationships between energy use and CO_2 emissions. First, let us examine some findings pertaining to groups of countries. For example, in the case of the United States, China, and India, a group of superpowers, Khochiani and Nademi (2020) find that GDP has a positive relationship with CO_2 in all three countries. Additionally, Wolde-Rufael and Idowu (2017), in a comparative analysis, find that China and India both exhibit similar trends showing that income contributes to CO_2 emissions as well. In a study of 17 transitional economies between 1997 and 2014 using the Dynamic Ordinary Least Squares technique, Mitić et al. (2017) found a significant and long running cointegrating relationship between GDP and CO_2. Mitić et al. (2017) also, quite interestingly, were able to show that a 1% increase in GDP led to a 0.35% increase in CO_2 emissions implying that there is a moderate unidirectional relationship between GDP and CO_2 emissions in these economies. In a study of five Western African countries, Ameyaw and Yao (2018) also found unidirectional causality running from GDP to CO_2 emissions. They are quick to point out that while CO_2 emissions in Africa are relatively insignificant compared to global emissions, emissions in the countries studied show a continuous growth which is a cause for concern as Africa continues to develop. Additionally, Ameyaw and Yao (2018) fill a gap in the literature by creating an algorithm that forecasts future emissions in the selected countries again showing that emissions will continue to rise with GDP growth. In another study, Ben Jebli and Hadhri (2018) find that, within the top ten international tourism countries, there is also a unidirectional causality running from CO_2 to economic growth. The authors fill an important gap in the literature by examining international tourism's effects on CO_2 emissions. It seems clear that tourism increases GDP and energy use which in turn also increases CO_2 emissions suggesting the need to transition to cleaner energy in tourist havens. Finally, Andreoni and Galmarini (2016), in a study of 33 countries between 1995 and 2007, found that GDP growth is a significant predictor of increasing CO_2 emissions. Similar to the Ben Jebli and Hadhri (2018) study, the authors suggest improvements in energy efficiency as they conclude most of the CO_2 emissions are related to energy production and usage.

Moving to a broader examination of the relationship between GDP and CO_2 emissions, some of the literature uses much larger sample sizes while some even conduct a world analysis of the relationship. For example, in two global studies conducted by Dong et al. (2019) considering 128 countries, they find that (1) population size and economic growth significantly influence CO_2 emissions (2018) and (2) economic growth and energy intensity significantly increase CO_2 emission levels. Similarly, Wu and Xie (2020: n.p.), in an analysis of 26 OCED and 52 non-OCED countries, found that increased income facilities increased energy usage and CO_2 emissions. More bluntly, Wu and Xie (2020:

n.p.) suggest that "per capita national income positively affects CO_2 emissions, meaning that income growth will accelerate emissions." Similarly, Saleh and Abedi (2014), in a panel analysis of World Bank member countries, found that in all three of the panels there was generally a one-way causal relationship running from GDP and CO_2. Most interesting was their finding that this relationship was especially intense in countries with relatively high levels of economic growth. This may imply that such dramatic levels of increasing growth are also ones that are hastily industrializing leading to more intense usage of inefficient methods of energy production thus contributing to high CO_2 emissions. In essence, it is vital to transition to a green energy economy. In a study of world economies, Lane (2011) notes that CO_2 emissions are closely linked to GDP. Similarly, also related to energy usage, Chen et al. (2016) found, in a study of 188 countries between 1993 and 2010, that GDP increases led to more energy consumption which generally increased CO_2 emissions overall. Finally, in a study of 51 countries with varying income levels, Chaabouni and Saidi (2017) found bidirectional causality between CO_2 and gross domestic product per capita. This study is particularly interesting as it was the only literature found showing a positive relationship running between GDP and CO_2 emissions that was bidirectional thus confirming the feedback hypothesis. All the other literature was generally unidirectional falling under the growth hypothesis previously outlined.

While the literature discussed confirmed a relationship between GDP and CO_2 emissions, other articles showed evidence of the Environmental Kuznets Curve (EKC). According to Chen et al. (2016:421), the EKC "sets emissions of environmental pollutants to be a function of income, and the relationship between income and environmental quality is depicted by an inverted U-shaped curve." Essentially, the EKC hypothesizes that CO_2 emissions rise with GDP up until a certain point. When that point is reached, CO_2 emissions begin to decline while GDP continues to rise resulting in an inverted U-shaped curve. The EKC was found in several of the studies examined. For example, Cosma et al. (2020), using a panel analysis, confirmed the EKC in a study of 31 European countries between 2000 and 2016. This finding may be attributed to the study's relatively small scope of analysis as the previous literature typically considered larger periods. One might suggest that between 2000 and 2016 the 'information economy' began to take shape resulting in GDP growth without the consequence of higher CO_2 emissions which is what the EKC essentially hypothesizes. Guo et al. (2020), in a study of 73 countries, also found that the EKC is valid but only in middle- and high-income countries which may also relate to the rise of the information economy in higher and middle-income countries. In contrast, Chakravarty and Mandal (2019), in a study of 57 economies, also confirmed the EKC but found it within both developed and developing countries. Importantly, they only observed EKC for the pollutant CO_2 but not for other greenhouse gas emissions. Chakravarty and Mandal (2019:222) are cautionary and state, "we should not blindly rely on EKC hypothesis thinking income will automatically take care of all types of environmental problem. Rather, growth with accountability with the environment is the way forward." Finally, related to the EKC, Afridi et al. (2019), in a study of SAARC countries, found an N-shaped relationship between GDP and CO_2 emissions. This essentially means that CO_2 rises with GDP, then falls, then rises once again with GDP created an N -shaped relationship. Interestingly, this was the only study retrieved that displayed such a relationship. Now we can examine the literature relating to the relationship between energy consumption, FDI, and urbanization on CO_2 emissions.

Literature on the Relationship of Other Variables on CO_2

As mentioned previously, some of the studies concerning the relationship between CO_2 emissions and GDP also included analysis considering other variables such as foreign direct investment, urbanization and energy consumption. This section will examine studies that focused more or less on these variables.

Energy Consumption

The relationship between energy consumption and GDP has been examined in several of the studies within this literature review. Some of these studies found multivariate relationships between energy consumption, GDP, and CO_2 emissions, implying, as previously mentioned, that energy consumption may lead to GDP increases which may in turn lead to increased CO_2 emissions. For example, in a study by Afridi et al. (2019), the authors found that energy consumption and CO_2 have a positive relationship in SAARC countries. This same study suggested an N-shaped relationship between GDP and CO_2 which may imply that the continued reliance on inefficient and environmentally unfriendly forms of energy within SAARC countries may result in increased CO_2 emissions independent of GDP growth. Fernández -Amador et al. (2017:278) also found a similar relationship between CO_2 and energy consumption but also suggested that "patterns and energy usage are in general dirtier in terms of CO_2 emissions." Wolde-

Rufael and Idowu (2017) also confirm the relationship between increased energy consumption and increased CO_2 emissions in a study of China and India.

Foreign Direct Investment

According to OECD (n.d.), foreign direct investment (FDI) "is a category of cross-border investment in which an investor resident in one economy establishes a lasting interest in and a significant degree of influence over an enterprise resident in another economy." Some of the literature examines the relationship between FDI and CO_2 emissions and is included here to act as a control variable.

Omri et al. (2014), in a study of 54 countries between 1990 and 2011, found a bidirectional causality between economic growth and FDI in all of the countries studied. They also found bidirectional causality between FDI inflow and CO_2 in the countries excluding Europe and North Asia. This may imply the existence of the pollution haven hypothesis (PHH) as the relationship between FDI inflow and CO_2 was only found in developing countries. According to the PHH, environmental regulations are typically lacking in developing countries. Because of this, investors are more likely to gravitate toward these countries in an effort to avoid the environmental regulations in their own countries. Therefore, foreign investors, usually through foreign direct investment, benefit from relatively weak environmental regulations. Bakirtas and Cetin (2017:18274) suggest that the outcome of this is an increase in environmental pollution as FDI rises "especially in developing countries." Similarly, Boachie Yiadom and Mensah (2021) found, in a study of 36 African economies, that FDI worsens the quality of the environment as measured by CO_2 emissions.

Gini

According to Hayes (2021: n.p.), the Gini index, or Gini coefficient, "is a measure of the distribution of income across a population." Gini is typically used as a measure for economic inequality and was first developed by Corrado Gini in 1912. A higher Gini translates to higher economic inequality. But, as Hayes (2021) mentions, the Gini index has its problems. Mainly, the Gini index is reliant on accurate GDP and income statistics that may not be readily available for all countries. Additionally, Gini is merely a single statistic that lacks the ability to show the shape of the distributions of income. Because of this, it is difficult to examine where inequality is taking place as it is only expressed as a single number. Nonetheless, some of the studies examined showed the relationship between the Gini index and CO_2 emissions.

In a study of G20 countries, Chen et al. (2020) suggest that Gini and CO_2 are not significant overall. Still, they find that, within developing countries, Gini and CO_2 have a significant relationship between one another. This could be a result of gaps in Gini data but, nonetheless, it follows that developing countries likely have greater gaps in income because of uneven development. Guo et al. (2020: n.p.) also examined the relationship in a study of 73 countries but merely found that "income inequality has widely divergent impacts on CO_2 emissions across country groups with different income levels." Additionally, they state that income inequality has a relatively small effect on emissions overall and that the variance is mostly explained by “the degree of country risk.” Considering another study with a similar sample size, Wu and Xie (2020), in a study of 78 countries between 1990 and 2017, suggest that inequality reduces per capita CO_2 emissions in countries with “good” economic conditions. This may validate the previous finding that Gini is a more valuable determinant of CO_2 emissions in developing countries. Finally, Mittmann and Mattos (2020:404) conducted a study of Latin American countries and state that the “nonlinear impact of income inequality is mediated by the level of the GDP per capita—with the direction of the impact depending on the income level. This means that addressing only economic growth or only income distribution is not a reasonable option for most of the Latin American countries.” This suggests the need for a more holistic consideration of factors that influence CO_2 emissions in Latin America.

Urbanization

Populations have continuously moved in mass to urban centers throughout the modern era. In fact, according to Birch and Wachter (2011:3), 2010 was the first year where more than half global population lived in urban areas. Of those in urban areas, around 33 percent lived in large cities or a ‘megacity’. By 2050, it is projected that the proportion of those in urban areas will grow to around 70 percent. Considering the rapid consolidation of populations into urban areas, it is important to examine the effects of urbanization on CO_2 emissions.

A few studies examined the relationship between CO_2 emissions and urbanization alone. For example, a study of East Asian and Pacific countries from 1982 to 2014 found that urbanization significantly decreased CO_2 emissions for some of the countries studied (China, Japan, Hong Kong, and Mongolia). Yet, interestingly, they found that urbanization increased CO_2 emissions in South Korea, Singapore, and Macao (Mehmood and Manssor 2021). In a different study of countries in the Central African Economic and Monetary Community found that, between 1990 and 2019, there was a significant and long-running positive relationship between urbanization and CO_2 emissions (Ngong et al. 2022). Additionally, the authors argued for urbanization laws in order to slow the rapid rise in emissions. While these two studies examined the effect of urbanization on CO_2 alone, another study considered other variables similar to the controls found in our analysis.

Sikder et al. (2022) conducted a study analyzing the combined effects of industrialization, urbanization, economic growth and energy usage on CO_2 emissions. Focusing on 23 developing countries between 1995 and 2018, the authors found that, after considering the other variables, a 1% increase in urbanization resulted in a 2.32% increase in CO_2 emissions. Additionally, they found this increase in the short and long term and established a bidirectional causal relationship between the urbanization and CO_2 emissions.

Gaps in the Literature

GDP has shown to be a decent measurement of economic growth and progress and acts as a fair variable to test with CO_2 in order to show relationships between economic growth and climate change. When testing for this, most of the literature agreed that, while GDP may have its faults, it is a widely available metric and can provide insight into a nation's rates of economic growth. It seems clear that there needs to be more research in the area of what contributes to CO_2 emissions. Many of the studies lacked a complete consensus on a universal contributor to emissions overall. In fact, some even called into question the efficacy of some of the variables with respect to their measurement and interpretation. For example, energy consumption lacks consideration for what type of energy is being used. Foreign direct investment is usually only applicable to developing countries especially considering its relationship to CO_2 emissions overall.

Investigation of these variables on a global scale could be beneficial in finding what contributes to CO_2 emissions. Additionally, considering the aforementioned variables as controls for GDP, including FDI, urban variables, and energy consumption may shed some light on GDP's true effect on CO_2 emissions within countries and globally. We can test the relationship between these variables on CO_2 across countries and make valuable discoveries on what some of the main drivers are.

III. RESEARCH QUESTIONS

As previously mentioned, gross domestic product (GDP) has been continuously used as a tool to measure economic growth and progress within countries. While a great deal of the literature examined thus far has focused on the relationship between GDP and CO_2 emissions, many studies fail to consider other variables which have varying degrees of influence on CO_2 emissions. While GDP is a measure of how much an economy has grown, it fails to consider other forms of growth within countries. This thesis aims to contribute to the existing literature on sustainability by not only examining the relationship between CO_2 and GDP, but also by considering the relationships between other variables empirically associated with growth While this thesis focuses on growth-related variables, it is important to note that this is a cross-sectional study and therefore is not a study of growth over time. Thus, based on the literature, the research hypothesis is:

Hypothesis: There is a positive relationship between GDP and CO_2 at the cross-national level, controlling for other variables empirically associated with growth.

IV. ANALYSIS

Data and Methods

Since this study is concerned with the relationship between GDP and CO_2 emissions on a cross-national scale, it is necessary to utilize a dataset with country-level data. Data used for this study are derived from the World Bank's (2021) website utilizing their World Development Indicators, covering the year 2016 for 217 countries. The year 2016 was chosen based on its relatively high availability of data for each country. With the World Bank data, there are unfortunately some missing values for micro countries and disputed territories within each of the variables selected for this analysis. To address the missing values, the analysis excludes cases listwise to ensure that it is only performed on countries that have variable data available. Because of the exclusion of cases listwise, the original sample size of countries was reduced (n=146).

Variables

This study will use several variables that are important indicators of growth and environmental degradation. These variables are based on some of the studies examined within the literature review that appear to be common measures with respect to the scope of this thesis. All of the variables included are derived from the World Development Indicators. The dependent variable is *CO_2 emissions per capita*, represented as the number of metric tons of CO_2. The predictor variable is *Gross Domestic Product (purchasing power parity expressed in international (US) dollars)* or *GDP per capita*. Both CO_2 and GDP variables were log transformed in order to normalize the variance, address skewness, and allow for beta coefficients to be interpreted as a percent change within the regression model. Along with these variables, there are five other control variables selected based on what commonly appeared throughout the literature as significant predictors of emissions.

The control variables include *renewable energy consumption* (expressed as a percentage of total final energy consumption per country), *foreign direct investment* (expressed as a percentage of GDP for net inflows in current international (US) dollars), *population in the largest city* (expressed as a percentage of urban population), *urban population* (expressed as a percentage of total population), and *industry* (including construction, expressed as a percentage of GDP value added). All control variables are measured as proportions to allow the interpretation of differences between the logged dependent and independent variables as a form of percentage change.

To determine whether GDP has a positive relationship between CO_2, I performed a hierarchical linear multiple regression to evaluate the prediction of CO_2 from GDP while controlling for *renewable energy consumption*, *foreign direct investment*, *population in the largest city*, *urban population,* and *industry* variable. Model 1 contains the control variables ran with the dependent logged CO_2 variable. Model 2 adds the log transformed GDP predictor variable in order to examine the R-square change and the overall significance between GDP and CO_2 within the model.

Results

Because of the exclusion of cases listwise, the original sample size of countries was reduced to n=146 in Model 1 and n=141 in Model 2. In both Model 1 & 2, all variables were statistically significant ($p<.05$), except one of the control variables. The results of the multiple linear regression analysis in Model 2 showed that the *urban population* control variable is not a statistically significant predictor of CO_2 emissions ($p > .05$). Nonetheless, the results of the multiple linear regression analysis in Model 2 uncovered a statistically significant relationship between GDP per capita and CO_2 emissions, controlling for foreign direct investment, renewable energy consumption, population in the largest city, and the industry variable.

With these controls, the regression coefficient (B=0.996, 95% C.I., $p<.05$) associated with GDP per capita in Model 2 shows that with each additional 1% increase in GDP per capita, CO_2 emissions per capita increases by 0.996% with a standard error of .051, an almost perfect positive relationship. The R^2 value associated with Model 1 suggests that the control variables account for around 78.8% of the variation is CO_2 emissions per capita. The R^2 value associated with Model 2 suggests that, when adding GDP with the control variables, the variables account for 94.6% of the variation in CO_2 emissions per capita. Examining the R^2 change for Model 2, I found that GDP per capita explains an additional 14.8% of the variation in CO_2 emissions when including the control variables. These results indicate that, on a cross-national scale, GDP per capita and CO_2 emissions are strongly positively related (R=.918), confirming our hypothesis.

Table 1. Univariate and bivariate statistics

Variable	N	Mean	SD	CO_2 emissions per capita	Renewable energy consumption	Foreign direct investment	Population in largest city	Industry	Urban population	GDP per capita
CO_2 emissions per capita*	191	.672	1.449	1.000						
Renewable energy consumption	213	28.951	27.971	-.788	1.000					
Foreign direct investment	193	10.05	70.292	.047	.047	1.000				
Population in largest city	153	33.13	18.241	-.213	.118	.061	1.000			
Industry	196	24.42	10.421	.289	-.077	.094	-.067	1.000		
Urban population	214	60.315	24.071	.669	-.520	-.116	.062	.047	1.000	
GDP per capita*	194	9.388	1.160	.918	-.688	.222	-.038	.155	.736	1.000

**Note:* Values for CO_2 emissions per capita and GDP per capita have been log-transformed.

Table 2. Results: Two Regression Models

Model		Unstandardized Coefficients		t	Sig.	Correlations			Collinearity Statistics	
		b	Std. Error			Zero-order	Partial	Part	Tolerance	VIF
1	CO_2 emissions per capita	-.222	.260	-.851	.396					
	Renewable energy consumption	-.029	.002	-12.193	.000	-.788	-.718	-.463	.705	1.419
	Foreign direct investment	.002	.001	2.810	.006	.047	.231	.107	.970	1.031
	Population in largest city	-.013	.003	-4.256	.000	-.213	-.338	-.162	.955	1.047
	Industry	.029	.005	5.372	.000	.289	.413	.204	.980	1.021
	Urban population	.024	.003	8.723	.000	.669	.593	.331	.703	1.422
2	CO_2 emissions per capita	-8.269	.435	-18.998	.000					
	Renewable energy consumption	-.012	.001	-8.137	.000	-.788	-.568	-.161	.475	2.106
	Foreign direct investment	-.003	.000	-5.601	.000	.047	-.429	-.111	.703	1.422
	Population in largest city	-.011	.002	-6.602	.000	-.213	-.489	-.130	.949	1.053
	Industry	.021	.003	7.597	.000	.289	.542	.150	.962	1.040
	Urban population	-.003	.002	-1.629	.105	.669	-.137	-.032	.359	2.785
	GDP per capita	.996	.051	19.454	.000	.918	.855	.384	.232	4.305

V. DISCUSSION

The aim of this study was to determine the relationship between GDP and CO_2 emissions on a cross-national scale after controlling for other growth variables.

CO_2 Emissions and GDP

The results indicate a significant positive relationship between carbon dioxide emissions and gross domestic product on a cross-national scale. This suggests that countries that have a higher GDP per capita also have higher CO_2 emissions per capita. In developed countries, it is often suggested that such a relationship seems to hold true because of such rapid levels of economic growth. Increased spending on goods, increased car-centric transportation usage, and the service economy all require energy to function. As previously discussed, the majority of energy production around the globe comes from the burning of fossil fuels. Thus, it seems clear that with the increase of GDP leads to increased energy demand and usage leading to higher CO_2 emissions. Countries with lower GDP per capita in contrast have a lower demand in line with their lower level of economic development.

Finding GDP and CO_2 to be positively associated is in line with previous literature showing the direct positive correlation between the two. This applies to studies with smaller country sample sizes (e.g., Ameyaw and Yao 2018; Ben Jebli and Hadhri 2018; Andreoni and Galmarini 2016) and larger country samples (e.g., Dong et al. 2019; Wu and Xie 2020; Saleh and Abedi 2014; Chen et al. 2016; Chaabouni and Saidi 2017).

Other Variables

While the Gini coefficient was included in the literature review, it was left out of the analysis. The control variables below already explained much of the variation in GDP per capita. Adding the Gini coefficient to the model did not significantly increase the R score, nor was it significantly correlated when entered into the model.

I found renewable energy consumption (as a percentage of total final energy consumption) to be strongly inversely associated with CO_2 emissions per capita. This was expected as countries that depend more on renewable energy sources rely less on other unsustainable forms of energy production such as the burning of fossil fuels. The analysis showed that each 1% increase in renewable energy consumption there is a 0.12% decrease in CO_2 emissions.

Interestingly, I found that foreign direct investment (net inflows expressed as a percentage of GDP) to be weakly associated with CO_2 emissions. In Model 1 (not including GDP), I found that for each 1% increase in FDI inflows there was a .002% increase in CO_2 emissions. For Model 2 (including GDP), the direction switches resulting in a .003% decrease in CO_2 emissions per 1% increase in FDI inflows. FDI was the only variable tested that was not significant ($p>.05$), so it had the weakest effect on both models. This is likely because of the nature of the analysis and the fact that the FDI variable was expressed as a percentage of GDP. While the studies concerned with FDI all showed that FDI was positively associated with CO_2 emissions, this analysis had a greater sample size of countries which may have impacted the interpretation of the variable within both models.

The urbanization variables yielded some interesting results as well. Population in the largest city (expressed as a percentage of urban population) had a weak to moderate negative association with GDP. For each 1% increase in population in the largest city there was a -.013% and -.011% decrease in CO_2 emissions in Model 1 and 2 respectively. The percent urban variable (expressed as a percentage of a country's population living in urban areas) was also significant ($p<.05$) but had a much smaller impact on CO_2 emissions per capita.

Finally, the industry variable (value added, expressed as a percentage of GDP) was also significant ($p<.05$). For each 1% increase in industry, there was a .021% increase in CO_2 emissions.

Implications and Applications

This study, like many others before it, confirms that there is a direct correlation between GDP per capita and CO_2 emissions per capita even when controlling for other common contributors to CO_2 emissions. Because of this strong relationship, it may be time to abandon the growth maxim that drives such high levels of emissions and environmental degradation. While some of the Sustainable Development Goals are relatively uncontroversial in their aims, it is worth addressing SDG 8 once again. Since some of SDG 8's targets are primarily concerned with the continuous growth of the world's economies it should be discussed as to how we can create prosperity for the rest of the world without thrusting more emissions into the atmosphere. While many ideas are discussed throughout various academic circles, some new and borderline revolutionary ones are starting to appear.

A great example is the idea of *degrowth*. Degrowth "is a planned reduction of energy and resource throughput designed to bring the economy back into balance with the living world" (Hickel 2021:1106). While the term itself may garner criticism for being 'anti-growth', the aim of degrowth is not to eliminate growth or GDP all together. Rather, degrowth seeks to scale down the sorts of growth that are ecologically destructive, wasteful, and less necessary. For example, it may be appropriate to reduce the production of military arsenals, frivolous consumption goods, and the like, *especially* in high-income countries. As stated in the literature, it is the larger and more wealthy countries that produce the most emissions per capita and are thus the ones that especially need to 'degrow' in such industries. Rather than eliminate growth completely, degrowth seeks to promote growth in important and human-centered industry. These may be things such as healthcare, education, housing, and sustainable transportation. Rather than blindly pursuing growth for growth's sake, which leads to more emissions overall, it is necessary to pursue a smarter and more calculated growth. Ideally, a growth which is focused and interested in promoting sustainable solutions for the globe.

Furthermore, this study also confirms that countries with higher levels of renewable energy consumption have lower levels of CO_2 emissions. This implies the need for the globe to urgently abandon the burning of fossil fuels and instead embrace renewable energy sources. Without doing so, CO_2 emissions will continue to increase and further warm the globe beyond repair.

Limitations

A potential shortcoming of this analysis is how economic growth is measured. While this study employed the usage of GDP to represent growth, it is far from a perfect measure as I have previously discussed. It is clear that we cannot consider every possible aspect of growth within the countries used for this analysis.

Secondly, CO_2 was the only emission considered in this study. As previously discussed, CO_2 is not the only emission contributing to climate change and the greenhouse effect. While CO_2 holds the largest share of emissions, this study leaves out methane and nitrous oxide, both of which have their own unique effects on the atmosphere. Additionally, CO_2 was measured as *per capita*, not as a total from each country which may have yielded different results in countries with smaller or larger population sizes.

Lastly, not all of the world's countries were analyzed. Our analysis only considered 146 countries in both models. While some countries did not have the appropriate data available, countries were excluded listwise, nonetheless. For example, a country which had GDP data may not have had the FDI data available which excludes it from the model. Additionally, the analysis looked at countries in a block together rather than specifically examining individual countries in an effort to identify outliers. Moreover, this study was not longitudinal and can only assess correlation. Future research should examine these relationships longitudinally and assess casualty between the variables.

VI. CONCLUSION

In conclusion, this study has found GDP per capita and CO_2 emissions per capita to be positively and strongly related on a global scale. These results confirm previous literature linking GDP growth to increased CO_2 emissions. Policy must be considered with the aim of reducing exponential GDP growth in order to reduce CO_2 emissions overall. Such aims could be achieved by embracing a degrowth strategy and planned downscaling of particularly wasteful and unsustainable growth within industries that benefit the most industrialized countries. In the future, research should examine individual country cases in order to identify outliers and develop country-specific strategies with the aim of reducing emissions overall. If focus can be shifted towards renewable energy and scaled down growth, the goal of reducing carbon emissions and achieving a sustainable future may be possible.

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