Greenbacks and Carbon Tracks: the Evolution of Economic Development and CO2 Emissions

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1 Introduction

Climate change and the effects of global warming are some of the greatest threats to the future existence of humanity. Throughout the 20th century, many scientists conducted research that indicated the potential adverse effects of climate change, including increased temperature, higher sea levels, and extreme weather phenomena. The main force driving global warming is the production of Greenhouse Gases (GHG) like Carbon Dioxide (CO2), which, when released into the atmosphere, absorbs infrared radiation, increasing the planet's temperature. Human activity, like the production and use of coal, natural gas, and oil, has caused an increase in the total amount of CO2 in the atmosphere by 50% since the start of the Industrial Revolution 250 years ago. Even though there is overwhelming evidence to support the catastrophic effects of global warming, by the turn of the century, only 10% of countries had policies to reduce their GHG emissions, believing that reducing CO2 emissions could only come at the cost of their economy. This paper examines those claims on a country level, analyzing the relationship between CO2 emissions and economic development.

This topic has been researched extensively over the past 30 years, piquing the interest of economists and policymakers alike. Before the 2000s, researchers primarily focused on the theoretical relationship between emissions and development, with the Environmental Kuznets Curve or EKC hypothesis emerging as the dominant theory. The EKC hypothesis states emissions "exhibit inverted-U or 'Kuznets,' relationship with economic development," where the inverted-U shape refers to emissions increasing with development as a country industrializes. However, once a country meets a certain development threshold, elevated income levels, better education systems, and increased societal openness, among other factors, will increase demand for environmental quality, resulting in reduced emissions in the long run (Selden and Song 1994). There are countless papers from this time with evidence both for and against the EKC hypothesis, but definitive evidence has yet to emerge due to the complexity of the relationship between CO2 emissions and economic development.

As the effects of climate change became clearer, researchers focused on the causal relationship between emissions and development, emphasizing the importance of energy consumption. Antonakakis et al. (2017) state that the trade-off between CO2 emissions and economic growth is an 'ethical dilemma,' finding a lack of evidence to support that renewable energy is conducive to economic growth. They found that countries with high CO2 emissions correlate with high levels of economic development, historically and today. The authors suggest a 'change in mindset' to promote a-growth or degrowth to protect the environment, as renewable energy may not be feasible in the long run.

Singh et al. (2019) yield contrary results, stating policies that incentivize investment in renewable energy technologies are conducive to economic growth, emphasizing additional benefits from creating green jobs and constructing renewable energy infrastructure. Authors warn that countries must carefully consider what policies to enact, as country factors can significantly impact their effectiveness. They also find that economic growth from renewable energy investments is higher in developing countries. Their results agree with Marques and Fuinhas (2012), who add that renewable energy technologies are becoming increasingly reliable and sustainable as more countries invest in them. Chiu and Chang (2009) agree that renewable technologies reduce emissions but estimate that renewable energy must provide a minimum of 8.39% of a country's total power generation to start to mitigate emissions. Their results support the EKC hypothesis, suggesting a threshold for countries to meet before being able to reduce emissions.

Jaforullah and King (2015) find that using renewable energy reduces CO2 emissions and the demand for fossil fuels, causing the price of fossil fuels also to fall. The decrease in price makes it challenging for developing countries to justify investments in expensive renewable energy technology as shifts towards renewables simultaneously make fossil fuels more competitive. The varied results stem from each study covering different regions and periods, a lack of consistency in what variables are considered, how variables are defined, and omitted variable bias due to the immensely complex relationship between CO2 emissions and economic development.

This paper contributes to the existing research on the relationship between CO2 emissions and economic development by conducting a comprehensive analysis of panel data from 110 counties spanning the period 1990-2018. This 28-year period witnessed a remarkable shift in global perspectives on climate change, reflecting a paradigm change in human awareness of environmental issues. Consequently, this paper also critically evaluates the effectiveness of greenhouse gas reduction targets, a widely adopted policy tool used by countries in their efforts to curb CO2 emissions.

Our results indicate that the production and use of fossil fuels are essential to countries' economic development, with higher CO2 emissions correlated with increased economic development. Additionally, we failed to find evidence supporting GHG reduction targets as an effective tool to reduce emissions. Countries that have started to reduce emissions have been unable to do so without first developing a dependence on fossil fuels to fuel their development, supporting the existence of an EKC curve.

The rest of the paper is organized as follows: Section 2 describes the dataset and sources for each variable included. Section 3 breaks down the data, including summary statistics and visualizations explaining the relationship between emissions and development. Section 4 includes regression results and their implications. Section 5 concludes the paper. Tables are found at the end of the paper in the Tables section.

2 Data

The primary dataset used in this analysis is Emissions by Country from The Global Carbon Project (1750-2022). It contains estimations of the dependent variable, CO2 emissions per capita by year, measured in metric tons of CO2. CO2 is the most common GHG produced by burning fossil fuels like coal, natural gas, and oil. For the past 200 years, we have relied almost exclusively on the burning of these resources to power our vehicles, cities, and industries. Our reliance on them makes it challenging to reduce CO2 emissions, as the world would cease to function if we ran out overnight. As countries embraced industrialization, their economy and CO2 emissions grew at unprecedented rates, making the challenge of our century to decouple their simultaneous growth. This dataset only contains CO2 emissions data, so additional datasets were needed to determine the relationship between CO2 emissions and economic development.

The first independent variable is Gross domestic product (GDP) per capita by year, measured in 2017 international dollars. The GDP measures the value of all goods produced by an economy in a given year. GDP measures how an economy evolves and grows yearly, making it a classic indicator to proxy economic development. The GDP dataset was downloaded from The World Bank (1990-2022) and includes observations on a country level. Comparing GDP per capita to CO2 emissions allows us to estimate how changes in output and production affect CO2 emissions. Additionally, we can determine how policies designed to reduce the effects of climate change impact the economy.

The subsequent independent variable is the Human Development Index (HDI) by year, another measure of economic development at the country level. The HDI dataset was downloaded from the United Nations Development Program (1990-2021). This composite index has multiple components falling under three general categories: quality of life, education access, and living standard. Some variables used in this index are gross national income (GNI), average years of education, and life expectancy. Using this index to measure economic development captures countries' economic well-being and the population's quality of life. Including HDI allows us to capture the adverse effects on economic development's social aspects rather than just monetary aspects.

Next is energy intensity measured in kilowatt-hours per dollar, which measures how efficiently an economy consumes energy. Energy intensity is calculated by the amount of energy (measured in kilowatt-hours) it takes to produce one unit of economic output (measured by GDP). Energy consumption is the most important variable connecting CO2 emissions to economic development (Singh et al., 2019) (Antonakakis et al., 2017). The energy intensity dataset was downloaded from Our World In Data (1965-2018), with observations on a country level by year. Since CO2 emissions result from our societal need for power, energy intensity provides essential insights into the production of CO2 emissions. While economists have not been able to agree on the causal relationship between emissions, economic development, and energy consumption, it is unanimous in emission literature that they are highly correlated.

The final independent variable is a dummy variable indicating if a country has implemented a policy with greenhouse gas emission reduction targets. This variable was created using the Climate Policy Database (1991-2023), which lists all climate-related policies, laws, and mandates ratified by any nation or supranational government body like the European Union. The subset of policies used in this analysis is all policies that have GHG reduction targets. This dataset gives insights into what countries are trying to reduce or limit their emissions and when they started. This dummy variable allows us to see if government policies designed to reduce GHG emissions are effective and if there is any correlation with economic development. The next section includes summary statistics and visualizations for each variable.

3 Summary Statistics and Visualizations

3.1 Summary Statistics

All tables can be found at the end of the paper in the tables section. The summary statistics for the dataset give us key insights into the distribution of CO_2 emissions across countries. The first columns to examine are Total CO_2 and CO_2 Per Capita, which have means of 245.35 $MtCO_2$ and 4.65 $MtCO_2$ per capita. These numbers represent the average amount of CO_2 a country emits annually. However, this mean is a bad estimator of CO_2 emissions. The standard deviation of these variables is 891.07 and 5.49, respectively. One standard deviation to the left will be a negative value for both variables. Since no country in this dataset has negative CO_2 emissions, this indicates a large right skew. The five-number summary shows us the median, 25th, and 75th percentiles, which are 25.47, 4.13, and 147.81 $MtCO_2$, respectively. The large difference in range for the second and third quartiles is another indicator of a right skew in the data. Total CO_2 emissions are not used for a majority of the analysis in this paper. However, it is important to note that China, the US, and India generate over 50% of total CO_2 emissions today. The large quantities of CO_2 these countries produce must be considered in global treaties like the Paris Climate Agreement, as the burden of reducing CO_2 emissions is not shared equally. CO_2 per capita has a median, 25th, and 75th percentile of 2.36, 0.62, and 7.29 $MtCO_2$ per capita, respectively, with Trinidad and Tobago having the largest CO_2 per capita in 2010 with 33.29 $MtCO_2$. Using per capita measures of CO_2 allows us to measure the impact of emissions relative to a country's population, as larger countries will have large total emissions to satisfy their population's demand for energy. During this period, Bahrain had the largest average CO2 per capita, and Burundi had the lowest average CO2 per capita.

GDP per capita has the same large right skew that we see for CO2 emissions. The mean for this dataset is $15305 with a standard deviation of $17067. One standard deviation to the left yields negative values, which is impossible as no country can produce negative output. Both variables having this skew indicate the large differences between countries and their economies, which is another factor to keep in mind to reduce CO2 emissions. Since countries do not have the same financial ability to reduce climate change, their contributions to reducing emissions will be smaller. The GDP per capita five-number summary shows us that more than 50% of countries have a GDP below the mean. The range of the fourth quartile is $109368, showing the wide range of values the largest and above-average-size economies can take on. Luxembourg had the largest GDP per capita of $131630 in 2021, and Mozambique had the smallest GDP per capita in 1992 of $287.66. During this period, Luxembourg had the largest average GDP per capita, and Burundi had the lowest average GDP per capita.

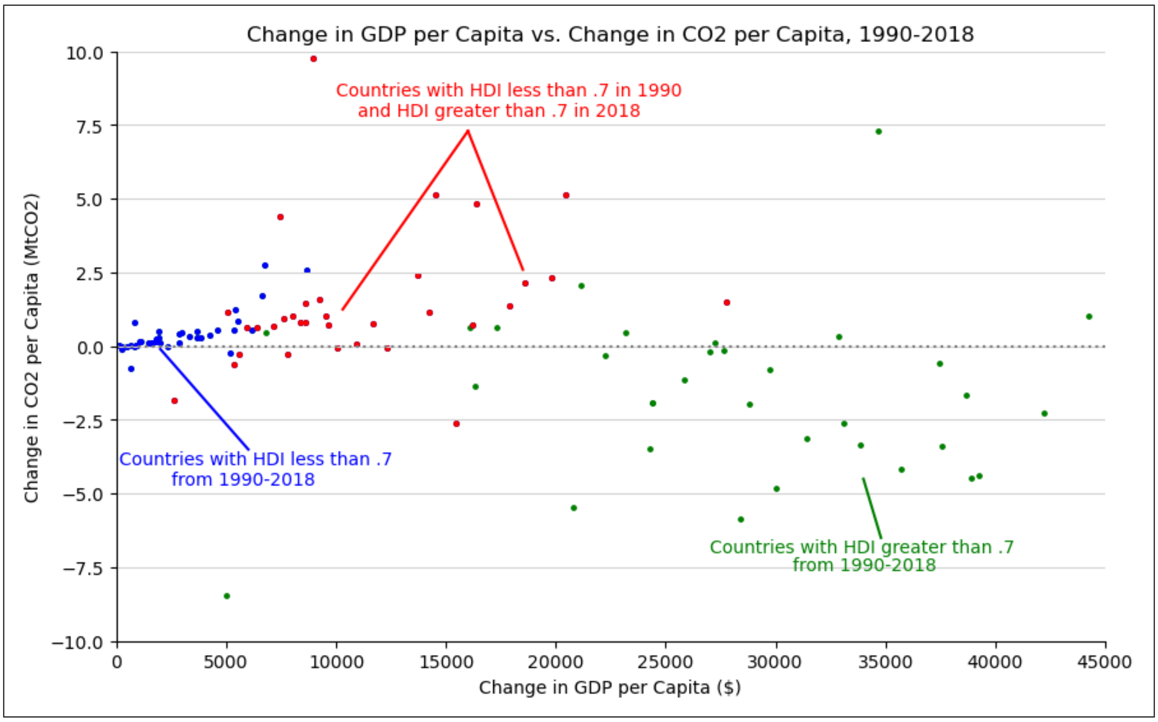
HDI has a mean of .67, which indicates the world's average level of economic development in this period. The values in the summary statistics for HDI do not provide much insight into our actual data. This variable, however, appears to resemble a normal distribution more than any other variable due to the median and mean being relatively close to each other. One standard deviation in either direction still covers possible values for this variable but also indicates that the HDI has some right skew. During this period, Norway has the largest average HDI, and Niger has the lowest average HDI.

Energy intensity has the least observations due to data being unavailable past 2018. This variable has the same distribution issues as the other variables, as one standard deviation from the mean will result in values outside of the variable's range. The difference between the 75th percentile and the maximum value for energy intensity indicates that few countries have very poor energy efficiency. The data is mostly clustered around the mean and within one standard deviation. Bahrain had the largest energy intensity of 23.14 in 1991, and Burundi had the smallest energy intensity of 0.21 in 2005. During this period, Bahrain had the largest average energy intensity, and Burundi had the lowest average energy intensity.

Finally, the dummy variable GHG Policy Ratified has a mean of 0.301 and a standard deviation of 0.46. A mean of 0.305 tells us that, on average, over the last 31 years, countries have only had GHG Policies implemented to reduce emissions and climate change 30.5% of the time. Only in the last 10 years have countries started to make an effort at the national level to reduce the effects of climate change. Since this is a dummy variable, all values will be 1 or 0. Hence, the 5-number summary provides no information on the dataset or variable. Unfortunately, a majority of these policies were only implemented after 2010, limiting our ability to examine their lasting impact on CO2 emissions.

3.2 Data Visualization

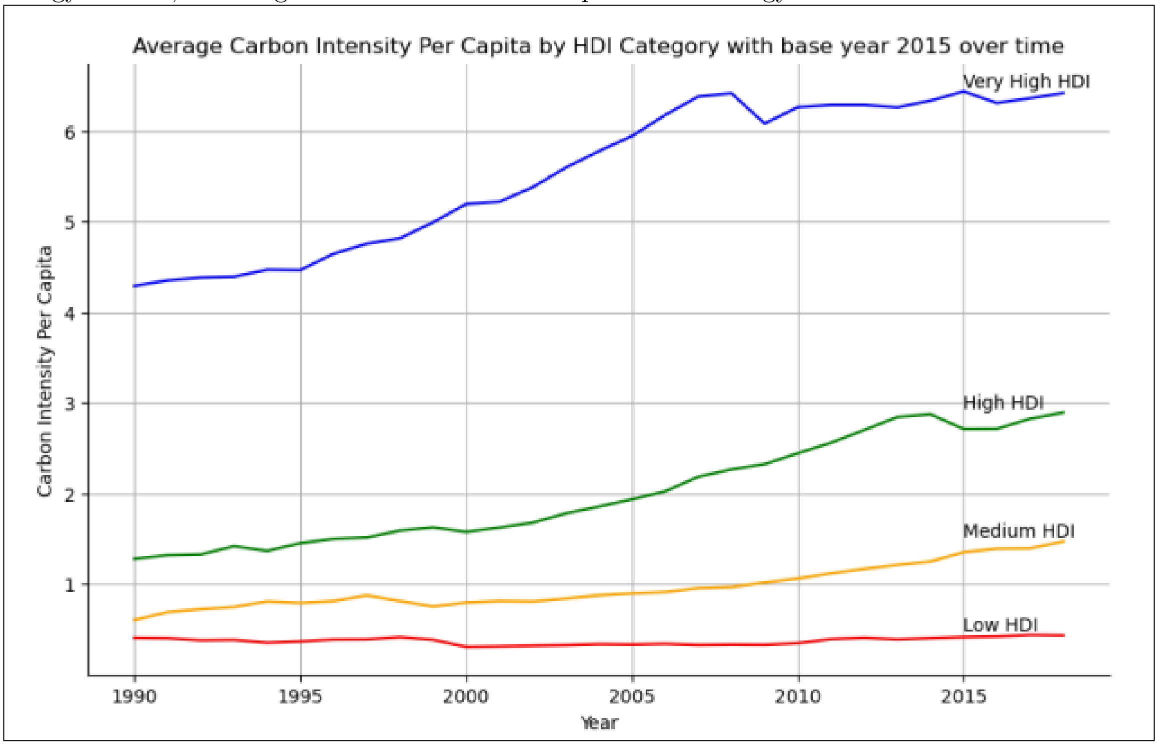
The graph below shows the relationship between improvements in economic development (measured by change in GDP per capita) vs. the change in CO2 per capita from 1990-2018. The green dots indicate countries with high economic development levels; these countries had a 'High' or 'Very High' HDI from 1990-2018. The blue dots indicate countries with low economic development levels; these countries had a 'Low' or 'Medium' HDI from 1990-2018. The red dots represent countries that moved from a 'Low' or 'Medium' HDI in 1990 to a 'High' or 'Very High' HDI by 2018. The red dot countries have had significant economic development during this period, and they have also had proportionally large increases in CO2 per capita to reach these increased levels of development.



This graph illustrates how the green countries, ones that were at 'High' and 'Very high' levels of development, have been able to increase their GDP per capita significantly during this period while also reducing their CO2 per capita, suggesting they have crossed the threshold requirement for renewable energies and development to reduce emissions, but not at the cost of GDP. The low-development countries see a similar effect as the red observations, where larger increases in GDP per capita also increase CO2 per capita. These countries are on a similar path to the red ones by improving their economic development, but this comes at the cost of higher emissions.

Over 80% of the world's power generation comes from fossil fuels (Antonakakis et al., 2017), and countless scientific studies have made it clear that our current emissions levels are not sustainable in the long run. As the population increases and our global demand for power generation continues to increase, CO2 emissions will only become more abundant, especially if we do not adequately invest in renewable energy technology to make them more affordable and reliable energy sources. In order to allow for continued economic development globally, the shift to renewable technologies needs to be a top priority for all countries, especially countries with high economic development due to their high carbon intensity and greater economic capacity to transition to low-carbon technologies.

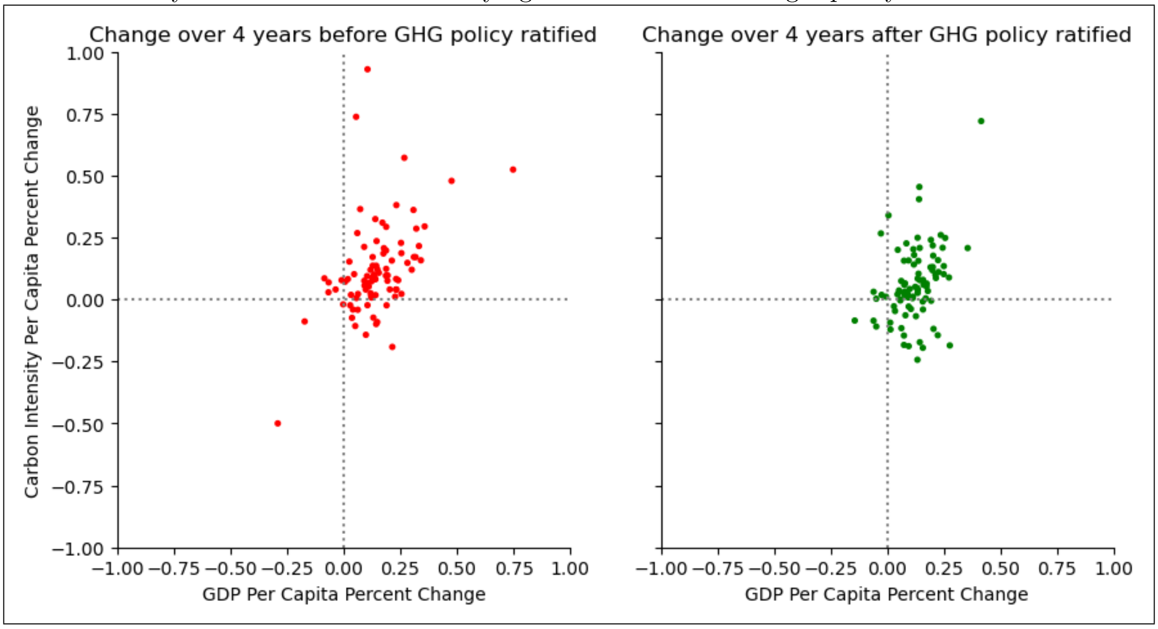
This next figure includes a new variable called carbon intensity per capita, which is CO2 emissions per capita divided by energy intensity, measured in metric tonnes of CO2 per capita per kilowatt-hours per dollar (MtCO2/kWh/$). Carbon intensity per capita measures a country's energy efficiency relative to its CO2 per capita, or intuitively, how carbon-intensive a country's energy consumption is. Higher values indicate that a country produces more CO2 emissions per capita per unit of energy consumed, implying the use of more carbon-intensive energy sources like fossil fuels or inefficient energy consumption. Lower values indicate a more energy-efficient country or cleaner energy sources, resulting in less carbon emissions per unit of energy consumed.



This graph shows the relationship between the level of economic development (measured by HDI) and the average carbon intensity of countries within each level of economic development. Countries with high levels of economic development have always had higher carbon intensity. However, despite higher levels of income and a greater economic capacity to reduce their CO2 emissions, developed countries have not made progress in reducing their emissions. This graph uses an HDI base year of

2015, meaning levels of economic development are based on a country's HDI in 2015. Using a base year is essential to prevent changes in average carbon intensity per capita for each HDI category from a country moving into a new HDI category. Of the 110 countries in this data, 73 changed economic development levels based on their HDI from 1990 to 2022. The graph contains data up to 2018; countries have started stabilizing their carbon intensity by this point. While this represents a transition towards more renewable energy and less carbon-intensive technology, a significant decrease in CO2 emissions and carbon intensity is needed to allow for similar levels of long-run growth our economies have seen during this period.

GHG reduction target policies are a popular policy tool used by countries to reduce CO2 emissions. The next figure compares the relationship between carbon intensity and GDP per capita for countries four years before and after ratifying a GHG reduction target policy.



The plots above standardize the year each county ratified a GHG policy. The graphs are split into four quadrants. The dots in the left quadrants indicate that GDP per capita has decreased relative to 4 years prior, with the right quadrants representing GDP per capita growth. The upper quadrants indicate higher carbon intensity per capita from 4 years prior, and the lower quadrants indicate lower carbon intensity per capita. The graph on the left with the red dots shows the change in GDP and Carbon Intensity per capita over the four years before ratifying a GHG policy. On the right is the change in GDP and Carbon Intensity per capita for the four years following a GHG policy's ratification. Comparing the number of countries in each quadrant, countries that are increasing GDP per capita while reducing carbon intensity increase by ten, indicating that certain policies have effectively reduced emissions without sacrificing development. However, there are no significant differences between the four years before and four years after ratifying GHG reduction policies. The effectiveness of these policies is questioned as four years after ratifying these policies, 64 of the 89 countries in this figure still saw increases in carbon intensity despite efforts to reduce CO2 emissions. The next section is a formal regression analysis of the data.

4 Results

The regressions use CO2 per capita as the dependent variable with GDP per capita, energy intensity, GHG policy ratified, country, and HDI as independent variables. HDI is a composite index that includes gross national income as an indicator of development. HDI and GDP cannot be included in the same regression without violating multicollinearity. Energy intensity is an essential variable to include. Since our consumption of fossil fuels causes CO2 emissions, measuring how efficient our consumption of these resources is helps explain variation between countries with high emissions and low output or vice versa. GHG policy ratified is included to identify how reduction target policies impact changes in emissions and if they are effective at reducing emissions. Additionally, a categorical variable for each country is included in each regression, allowing us to control for differences across countries.

Differencing was used to remove time series trends, converting GDP, CO2, and energy intensity per capita to changes in GDP per capita, change in CO2 per capita, and change in energy intensity. A natural log transformation was also applied to GDP per capita to make regression results easier to interpret. The Table 2 includes results from the following regressions:

1. $co2_i = \beta_0 + \beta_1 \; ln\_gdp_i + \beta_2 \; country\_fixed\_effects_i + \epsilon_i$
2. $co2_i = \beta_0 + \beta_1 \; ln\_gdp_i + \beta_2 \; ghg_i + \beta_3 \; country\_fixed\_effects_i + \epsilon_i$
3. $co2_i = \beta_0 + \beta_1 \; ln\_gdp_i + \beta_2 \; ghg_i + \beta_3 \; energy\_intensity_i + \beta_4 \; country\_fixed\_effects_i + \epsilon_i$

4. $co2_i = \beta_0 + \beta_1\ ln\_gdp_i + \beta_2\ ghg_i + \beta_3\ energy\_intensity_i + \beta_4\ medium\_hdi_i + \beta_5\ high\_hdi_i + \beta_6\ very\_high\_hdi_i + \beta_7\ country\_fixed\_effects_i + \epsilon_i$

Table 2 estimates the effects of changes in ln GDP per capita on CO2 emissions per capita. Specification (1) estimates that, on average, a 1% increase in ln GDP per capita is associated with a 2.574% increase in CO2 per capita. The coefficient is significant at the 1% level with an R-squared value of 0.083. The low R-squared value indicates that there is still significant variation in CO2 per capita that cannot be explained by changes in ln GDP per capita, which we knew before, as many external factors can cause changes in CO2 per capita. The intercept of -0.151 indicates that when there is no change in ln GDP per capita, CO2 per capita decreases by 0.151%. However, it is important to note that countries will rarely see a 0% change in GDP per capita in practical terms. An f-statistic of 26.711 indicates that the results are highly significant and changes in ln GDP per capita correlate with changes in CO2 per capita. Specification (1) is a simple model with no controls; it can give a good idea of the relationship but does not tell the whole story.

Specification (2) is the same as specification (1) but with a control variable for GHG policy ratified. Specification (2) estimates on average that a 1% increase in ln GDP per capita is associated with a 2.552% increase in CO2 per capita when controlling for GHG policy ratified. The coefficient for ln GDP per capita and the intercept are both significant at the 1% level. The R-squared value is similar to specification (1) as GHG policy does not have a significant effect on changes in CO2 per capita, meaning variation in CO2 per capita is still largely unexplained by changes in ln GDP per capita and GHG policies. The coefficient on GHG policy is -0.045, meaning that countries with a GHG policy ratified saw, on average, 0.045 metric ton decreases in CO2 per capita. However, this lacks statistical significance, and its confidence interval includes 0, meaning we cannot determine whether this effect is accurate or negative.

Specification (3) adds a control for change in energy intensity. The coefficient for change in ln GDP per capita is similar to the specification (1) and (2) results, estimating on average that a 1% increase in ln GDP per capita is associated with a 2.780% increase in CO2 per capita when controlling for GHG policy and energy intensity. The coefficient for GHG policy ratified has a slightly large magnitude and is significant at the 10% level. However, it still has a 95% confidence interval that includes 0, indicating the effect may not even be negative. Change in energy intensity has a coefficient of 0.551, which is significant at a 1% level and indicates that a one-unit change increase in energy intensity per capita is associated with a 0.551 metric ton increase in CO_2 per capita. This makes sense as increases in energy intensity are decreases in energy efficiency. So, as energy intensity increases, a country is using more fuel to produce a single unit of economic output. The R-squared values increase from specification (1) and (2) to 0.114, which is still low but indicates that more of the variation in CO_2 per capita can be explained when including energy intensity as a control variable.

Specification (4) adds another categorical variable for the HDI category to test for differences across groups, using low HDI as the reference group. This specification yielded similar results to specification (3) for ln GDP per capita and energy intensity, indicating a positive correlation with CO_2 per capita. The medium and very high HDI coefficients were not significant at any level, high HDI was at a 10% level. Across the groups, there was not sufficient evidence to suggest that there are significant differences across the HDI grouping for the relationship between CO_2 emissions and GDP. However, these regressions controlled for country effects, which treats each country as a different variable, so grouping the countries by HDI in the same regression would capture small effects mostly covered by differences across countries already. While the R-squared value for specification (4) is larger than specification (3), the f-statistic is nearly double in specification (3), indicating higher significance overall, indicating it is a better measure of the relationship between CO_2 per capita and ln GDP per capita. See Tables 2 and 3 for better estimates of differences between HDI grouping.

Table 2 gives statistically significant evidence that both ln GDP per capita and energy intensity are positively correlated with CO_2 per capita as hypothesized in econometric theory. These regressions fail to support GHG reduction targets as effective policies for reducing CO_2 emissions due to low or no statistical significance and 95% confidence intervals that include 0, meaning we cannot determine if there is a positive or negative association. One potential explanation for GHG reduction target policies having a positive association with CO_2 emissions could be due to global pressure to ratify the Paris Climate Agreement, even though many countries lack the economic strength to invest in renewable technologies. Many developing countries who ratified the agreement, like Pakistan, indicated in their 2015 nationally determined contribution plan that they anticipated a 300% increase in their emissions from 2015 to 2030 due to planned economic expansion in the energy and industrial sectors. Their contribution plan states that the country must prioritize its citizens and the economy over its emissions to ensure a stable future. Many other developing countries have similar issues, where they do have GHG reduction targets, but these targets are a secondary priority to economic expansion. As of 2015, nearly every country in this dataset had GHG reduction targets due to the Paris Climate Agreement. However, these targets are non-binding, and many countries undergoing rapid development, like Pakistan, will continue to increase emissions despite efforts to reduce them.

To further understand the differences between development, I split the dataset into four subsets based on their HDI category in the year 2015. Using the base year of 2015 allows us to compare differences between HDI groups without worrying about countries that moved to a higher or lower group during this period. Tables 2 and 3 regress the same variables as Table 2 but separates observations between low, medium, high, and very high HDIs. The regressions included in Table 3 are:

1. $co2\_low\_hdi_i = \beta_0 + \beta_1\ ln\_gdp_i + \beta_2\ country\_fixed\_effects_i + \epsilon_i$
2. $co2\_low\_hdi_i = \beta_0 + \beta_1\ ln\_gdp_i + \beta_2\ ghg_i + \beta_3\ country\_fixed\_effects_i + \epsilon_i$
3. $co2\_low\_hdi_i = \beta_0 + \beta_1\ ln\_gdp_i + \beta_2\ ghg_i + \beta_3\ energy\_intensity_i + \beta_4\ country\_fixed\_effects_i + \epsilon_i$
4. $co2\_medium\_hdi_i = \beta_0 + \beta_1\ ln\_gdp_i + \beta_2\ country\_fixed\_effects_i + \epsilon_i$
5. $co2\_medium\_hdi_i = \beta_0 + \beta_1\ ln\_gdp_i + \beta_2\ ghg_i + \beta_3\ country\_fixed\_effects_i + \epsilon_i$
6. $co2\_medium\_hdi_i = \beta_0 + \beta_1\ ln\_gdp_i + \beta_2\ ghg_i + \beta_3\ energy\_intensity_i + \beta_4\ country\_fixed\_effects_i + \epsilon_i$

Table 3 estimates the effects of changes in ln GDP per capita, GHG policy ratified, and change in energy intensity on changes in CO2 emissions per capita for countries with a low and medium HDI in 2015. Specifications 1-3 use observations from low HDI countries, and 4-6 use observations from medium HDI countries.

Table 3 specifications 1-3 indicate changes in ln GDP per capita, GHG policy ratified, and energy intensity that are not associated with changes in CO2 emissions at any significance level. The standard errors of the change in ln GDP per capita and GHG policy ratified are larger than the coefficients, indicating very low significance. The 95% confidence intervals for these variables all include zero as well, meaning we cannot determine if the effects of these variables are positive or negative at this level of development. The R-squared values range between -0.015 and 0.003, indicating essentially non-existent correlation. The f-statistics are also all less than 1, indicating low significance overall. These regressions provide much more information on the relationship between emissions and development than the results in Table 1. Specifications 1-3 all point towards changes in ln GDP per capita having little to no effect on changes in CO2 per capita. A possible explanation is that low HDI countries have largely unindustrialized economies, meaning increases in ln GDP per capita do not necessarily mean increases in CO2 emissions. Based on these regressions, we can determine that low HDI countries have minimal impacts on CO2 emissions. Additionally, we can infer that when these countries start to increase CO2 emissions, they will also have an increase in GDP per capita and overall level of development.

Specifications 4-6 include observations for medium HDI countries. Specification (6) provides the best estimate, indicating that, on average, a 1% increase in ln GDP per capita is associated with a 0.587% increase in CO2 per capita when controlling for changes in energy intensity and GHG policy. The coefficient is significant at a 1% level. GHG policy and change in energy intensity do not have significant coefficients, and 95% confidence intervals include 0, so we cannot determine if their effect is positive or negative. Specifications 4-6 have a higher R-square value than specifications 1-3, indicating that medium HDI countries have a stronger correlation between CO2 and GDP. However, a value of 0.177 is still very low, indicating lots of variation not explained by changes in GDP, energy intensity, or GHG policies. Specifications 4-6 also have a statically significant f-statistic. Based on these results, we can infer that medium HDI countries are all entering an industrial age. The GHG policy coefficient is estimated to be positive, likely due to many countries in this group being in a similar situation to Pakistan, pressured to join the Paris Climate Agreement despite not having the economic foundations to reduce emissions and prioritizing economic growth over reducing emissions. Interestingly, the coefficient for energy intensity was not significant in specification 6. A potential explanation is that early industrialization has such a large effect on ln GDP per capita and CO2 per capita that the level of energy intensity is irrelevant compared to the large increases in emissions and output. Table 4 covers high and very high HDI countries, the regressions included in Table 4 are:

1. $co2\_high\_hdi_i = \beta_0 + \beta_1\ ln\_gdp_i + \beta_2\ country\_fixed\_effects_i + \epsilon_i$

2. $co2\_high\_hdi_i = \beta_0 + \beta_1\ ln\_gdp_i + \beta_2\ ghg_i + \beta_3\ country\_fixed\_effects_i + \epsilon_i$
3. $co2\_high\_hdi_i = \beta_0 + \beta_1\ ln\_gdp_i + \beta_2\ ghg_i + \beta_3\ energy\_intensity_i + \beta_4\ country\_fixed\_effects_i + \epsilon_i$
4. $co2\_very\_high\_hdi_i = \beta_0 + \beta_1\ ln\_gdp_i + \beta_2\ country\_fixed\_effects_i + \epsilon_i$
5. $co2\_very\_high\_hdi_i = \beta_0 + \beta_1\ ln\_gdp_i + \beta_2\ ghg_i + \beta_3\ country\_fixed\_effects_i + \epsilon_i$
6. $co2\_very\_high\_hdi_i = \beta_0 + \beta_1\ ln\_gdp_i + \beta_2\ ghg_i + \beta_3\ energy\_intensity_i + \beta_4\ country\_fixed\_effects_i + \epsilon_i$

Table 4 estimates the effects of changes in ln GDP per capita, GHG policy ratified, and change in energy intensity on changes in CO2 emissions per capita for countries with a high and very high HDI in 2015. Specifications 1-3 use observations from high HDI countries, and specifications 4-6 use observations from very high HDI countries.

Table 4 specifications (3) estimates on average, a 1% increase in ln GDP per capita is associated with a 3.505% increase in CO2 per capita for high HDI countries holding GHG policy ratified, and changes in energy intensity constant. The coefficient for GHG policy is not statistically significant and includes 0 in the 95% confidence interval. Specification (3) indicates that a 1 unit increase in energy intensity is associated with a 0.596 metric ton increase in CO2 per capita, holding change in ln GDP per capita and GHG policy constant. The coefficient for change in ln GDP per capita and energy intensity are statistically significant at the 1% level. Specification (3) has an R-square value of .194, which is still low but indicates that some of the changes in CO2 emissions can be explained by the variables included in the regression. Additionally, an f-statistic of 4.195 is highly significant. The coefficient for change in ln GDP per capita is much larger than the Table 3 regressions for low and medium HDI and larger than the estimated effect in Table 2 specification (3). Breaking down the regressions by HDI grouping reveal how much high and very high HDI countries increase the global average for changes in CO2 emissions based on ln GDP per capita.

Table 4 specifications (6) estimates on average, a 1% increase in ln GDP per capita is associated with a 5.024% increase in CO2 per capita for very high HDI countries holding GHG policy ratified and changes in energy intensity constant. The coefficient for GHG policy is not statistically significant and includes 0 in the 95% confidence interval. Specification (3) indicates that a 1 unit increase in energy intensity is associated with a 0.711 metric ton increase in CO2 per capita, holding change in ln GDP per capita and GHG policy constant. The coefficient for change in ln GDP per capita and energy intensity are statistically significant at the 1% level. Specification (6) has an R-square value of 0.135, which is lower than in high HDI countries, and the f-statistic of 9.507 is highly significant. Very high HDI countries have the largest increases in CO2 per capita associated with an increase in GDP per capita.

Overall, tables 3 and 4 provide a lot of insight into the relationship between CO2 emissions and each level of economic development. Countries in the low HDI category are estimated to have no significant relationship between ln GDP per capita and CO2 emissions - the R-squared value was near 0. While countries in the medium HDI category have a significant relationship, the association is smaller than the estimated average global effect from Table 2. High and very high HDI countries have estimated associations of 0.8 to 2.7 percentage points higher than the estimated global average. By breaking down the observations by HDI category, it's clear that countries with higher levels of development have higher emissions and a stronger correlation between CO2 per capita and ln GDP per capita. These results align with the EKC hypothesis, low HDI countries have the smallest economies and lack industrialized capital. Medium HDI countries have the industrialized capital indicated by their higher emissions, which also comes with increased GDP per capita. High and very high HDI countries are the most industrialized countries, creating the most CO2 emissions and the largest economic output. Due to data not being available past 2018, it is hard to determine in this dataset if high and very high HDI countries have crossed a threshold to start reducing their emissions. To determine if emissions are declining, a non-linear regression would better estimate the effects.

Additionally, none of the regressions in Tables 3 and 4 yielded sufficient evidence indicating that GHG reduction targets are an effective tool for reducing CO2 emissions. Even for countries with very high HDI, we fail to find evidence that GHG reduction targets even reduce emissions, with each coefficient having a 95% confidence interval that includes 0.

5 Conclusion

This paper has examined the relationship between CO2 emissions and economic development, closely examining the effectiveness of GHG reduction targets as a viable tool to reduce CO2 emissions. Using

CO_2 emissions data combined with various indicators for economic development, we revealed that countries with medium, high, or very high HDI have a positive correlation between CO_2 emissions and GDP per capita, while low HDI countries did not. The regression analysis failed to find evidence supporting GHG reduction targets as an effective tool for reducing CO_2 emissions.

The results highlight our reliance on fossil fuels to grow our economies. Countries that have started to reduce emissions have been unable to do so without first developing a dependence on fossil fuels to fuel their development, supporting the existence of an Environmental Kuznets Curve (EKC) curve. As the effects of climate change continue to worsen, the need to invest in and transition to renewable technology becomes more urgent.

As more data is made available to the public, future research should be conducted on the effectiveness of GHG reduction policies. Many countries did not ratify a GHG reduction policy until 2015's Paris Climate Agreement. However, data was only available up to 2018. Repeating this analysis with data extending up to 2025 or 2030 would allow for a better understanding of the effectiveness of these policies as we transition to a climate-positive mindset.

6 References

6.1 Datasets

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6.2 Literature Review

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7 Tables

Table 1: Summary Statistics

	Total CO2	CO2 Per Capita	GDP Per Capita	HDI	Energy Intensity	GHG Policy Ratified
Count	3520	3520	3520	3520	3190	3520
Mean	245.356	4.652	15305.409	0.672	1.533	0.305
Std	891.076	5.490	17067.118	0.174	1.418	0.460
Min	0.000	0.000	287.661076	0.216	0.209	0.000
25%	4.138	0.618	3131.659	0.532	0.833	0.00
50%	25.465	2.368	8808.760	0.694	1.168	0.000
75%	147.809	7.290	22244.178	0.813	1.836	1.000
Max	11472.369	33.296	131630.774	0.962	23.142	1.000

Table 2: Simple Regressions

	Dependent variable: Change CO2 per capita			
	(1)	(2)	(3)	(4)
Change GDP per capita (ln)	2.574***	2.552***	2.780***	2.749***
	(0.492)	(0.490)	(0.531)	(0.517)
GHG Policy Ratified		-0.045	-0.050*	-0.042
		(0.032)	(0.030)	(0.034)
Change Energy Intensity			0.531***	0.537***
			(0.116)	(0.119)
Medium HDI				0.035
				(0.021)
High HDI				0.100*
				(0.059)
Very High HDI				-0.013
				(0.091)
Intercept	-0.151***	-0.143***	-0.130***	-0.189***
	(0.029)	(0.030)	(0.030)	(0.047)
Country Fixed Effects	Yes	Yes	Yes	Yes
Observations	3080	3080	3080	3080
R^2	0.083	0.084	0.114	0.117
Adjusted R^2	0.049	0.050	0.080	0.082
Residual Std. Error	0.530	0.530	0.521	0.521
F Statistic	26.711***	17.827***	13.457***	6.919***

Note: Table reports regression results for yearly changes in CO2 per capita. Each regression controls for country fixed effects. Column (1) estimates the effects of changes in GDP per capita (ln) on changes in CO2 per capita. Column (2) adds a control for GHG policy ratified. Column (3) adds a control for changes in energy intensity. Column (4) adds a categorical variable for HDI category, with 'Low HDI' as the reference category. Standard error reported in parenthesis and clustered by country. Significance stars: *p<0.1; **p<0.05; ***p<0.01

Table 3: Grouping by HDI: Low and Medium HDI in 2015

	Dependent variable: Change CO2 per capita					
	Low HDI			**Medium HDI**		
	(1)	(2)	(3)	(4)	(5)	(6)
Change GDP per capita (ln)	0.035	0.035	0.037	0.445***	0.451***	0.587***
	(0.049)	(0.049)	(0.050)	(0.089)	(0.090)	(0.122)
GHG Policy Ratified		-0.000	0.000		0.017	0.015
		(0.005)	(0.005)		(0.013)	(0.013)
Change Energy Intensity			0.031			0.305
			(0.023)			(0.203)
Intercept	0.004***	0.004***	0.003**	0.003	0.001	-0.003
	(0.001)	(0.001)	(0.001)	(0.004)	(0.004)	(0.005)
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	560	560	560	644	644	644
R^2	0.023	0.023	0.042	0.113	0.115	0.177
Adjusted R^2	-0.013	-0.015	0.003	0.080	0.081	0.144
Residual Std. Error	0.039	0.039	0.039	0.107	0.107	0.104
F Statistic	0.479	0.302	0.762	24.164***	12.759***	8.068***

Note: Table reports regression results for yearly changes in CO2 per capita. Each regression controls for country fixed effects. Columns (1) - (3) include countries with a low HDI in 2015. Columns (4) - (6) include countries with a medium HDI in 2015. Column (1) and (4) estimates the effects of changes in GDP per capita (ln) on changes in CO2 per capita. Column (2) and (5) adds a control for GHG policy ratified. Column (3) and (6) adds a control for changes in energy intensity. Standard error reported in parenthesis and clustered by country. Significance stars: *p<0.1; **p<0.05; ***p<0.01

Table 4: Grouping by HDI: High and Very High HDI in 2015

	Dependent variable: Change CO2 per capita					
	High HDI			**Very High HDI**		
	(1)	(2)	(3)	(4)	(5)	(6)
Change GDP per capita (ln)	3.043***	3.030***	3.504***	4.794***	4.740***	5.024***
	(0.960)	(0.980)	(1.157)	(0.974)	(0.964)	(1.009)
GHG Policy Ratified		-0.013	-0.019		-0.067	-0.077
		(0.028)	(0.027)		(0.064)	(0.060)
Change Energy Intensity			0.596***			0.711***
			(0.223)			(0.205)
Intercept	-0.179***	-0.176***	-0.175***	-0.238***	-0.206***	-0.176***
	(0.057)	(0.061)	(0.066)	(0.039)	(0.048)	(0.049)
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	756	756	756	1120	1120	1120
R^2	0.147	0.148	0.194	0.096	0.097	0.135
Adjusted R^2	0.116	0.115	0.161	0.063	0.063	0.101
Residual Std. Error	0.404	0.404	0.393	0.796	0.796	0.780
F Statistic	10.037***	4.845***	4.195***	24.215***	12.569***	9.507***

Notes: Table reports regression results for yearly changes in CO2 per capita. Each regression controls for country fixed effects. Columns (1) - (3) include countries with a high HDI in 2015. Columns (4) - (6) include countries with a Very High HDI in 2015. Column (1) and (4) estimates the effects of changes in GDP per capita (ln) on changes in CO2 per capita. Column (2) and (5) adds a control for GHG policy ratified. Column (3) and (6) adds a control for changes in energy intensity. Standard error reported in parenthesis and clustered by country. Significance stars: *p<0.1; **p<0.05; ***p<0.01