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CO_2 Emissions, Economic Growth, and Energy Consumption in G7 and BRICS Countries

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Abstract: This research set out to investigate whether economic growth has an impact on CO_2 emissions in G7 and BRICS countries, and whether the Paris Agreement has been effective in respect to CO_2 emissions by successfully analysing each of the five null hypotheses. This was achieved through analysing the 12 countries between 1990 to 2019. A panel AMG method was applied as the main econometric estimator, being able to account for both CD and heterogeneity, it seemed to be the most efficient panel estimation method. The findings differing when analysing the all countries in the panel together, to when examining individual relationships. Alongside this, cointegration and causality tests were applied to help understand the relationship between CO_2, GDP, and energy consumption. The robustness of the panel data analysis is checked by employing both per capita and real figures for all 12 countries.

A key finding from this study is that the EKC hypothesis does not stand true for all individual countries. Although, a long-run equilibrium relationship between CO_2 emission, GDP, and energy consumption for the entire panel is found for real level figures, individually the results vary. Saying this, the findings suggest a long-run equilibrium relationship between CO_2 emissions, GDP, and energy consumption and strong causality between variables.

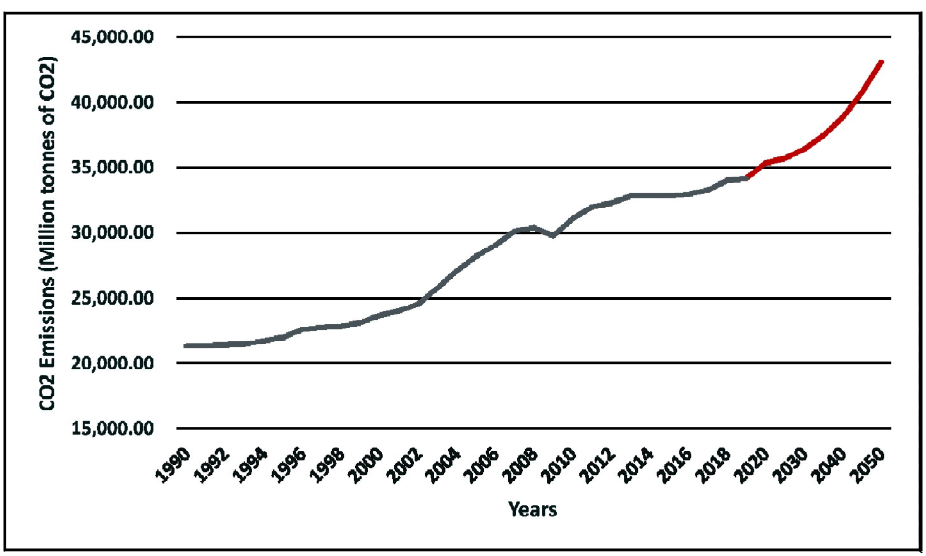
Alongside this, the decline in G7 countries real level CO_2 since the signing of the Paris Agreement and the results of the optimal GDP level both support the differences between BRICS and G7 countries. These findings support the Green Solow Model (Brock and Taylor, 2010), suggesting that once a countries growth rate stabilises, technological progress can lead to a decline in CO_2 emissions, tending towards net zero emissions. Acknowledging that continued economic growth brings greater harm to the environment is critical for the design of appropriate developing strategies for emerging economies and understanding whether the ambitious aims of achieving net zero emission by 2050 can be achieved at the current pace of change, this reinforces the Paris agreement's suggestion of developed countries taking the lead on reducing emissions seem to be a far and realistic predication based on this studies results.

1. Introduction

In 2019, over 11,000 scientists from around the world declared that Planet Earth is facing a climate emergency, with greenhouse gas (GHG) emissions rapidly rising (Ripple *et al.*, 2019). This increase in emissions is the consequences of many economic activities which, directly or indirectly, involve the combustion of fossil fuels, resulting in the emissions of carbon dioxide (CO_2). Figure 1 shows the growth in world CO_2 emissions from 1965 to 2019 (BP, 2020), with the red section representing the predicted values of CO_2 emissions until 2050 if we were to remain 'business as usual', forecasting 43.08 billion metric tonnes in 2050 (Tiseo, 2021).

This surge has led to CO_2 emissions becoming a global externality, caused by unregulated markets excessively producing because no price has been put on external damages (Nordhaus, 2013). An economic concept known as the invisible hand was first introduced by Adam Smith in 1759. The theory suggested that the invisible hand of markets set prices to balance costs and desires, however, an unregulated invisible

Figure 1 : World CO_2 Emissions (1965 – 2050)



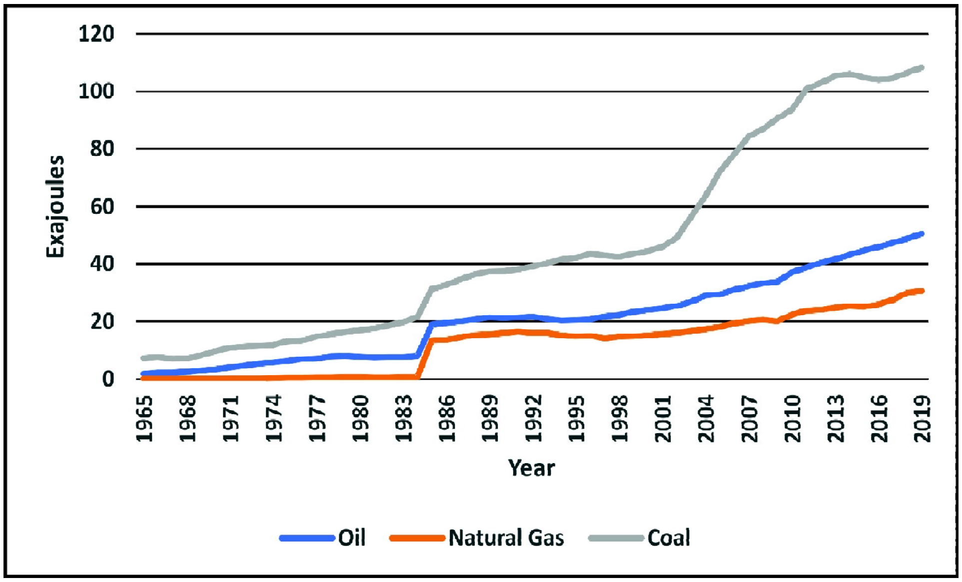
hand sets the prices incorrectly when there are externalities, therefore creating a need for intervention (Smith, 1797). The intervention needs to be global, ensuring that the benefits of participation outweighs the costs, and eliminate the incentives to free ride. Global warming is an unusual economic phenomenon which differs to other global issues because there is currently no higher world power in place to implement policies for slowing climate change, this means disinterested countries can easily opt out of the shared responsibility that is needed for managing global warming.

Current international agreements have been put in place by the United Nations Convention on Climate Change (UNFCCC), ratified in 1994. The first binding international agreement on climate change was the Kyoto Protocol, 1997. The protocol focused on advanced economies, classified as 'Annex B' countries, each holding a binding reduction target for GHG emissions. Under the "common but differentiated responsibility and respective capabilities" principle, a heavier responsibility was placed on industrialised economics, as they were said to be liable for higher levels of GHG emissions (United Nations, 1998, p.10). Empirical research has concluded the protocol was effective in reducing targets for Annex B countries, however the effects of per capita income have worsened since the signing of the protocol, finding a negative relationship between industrial production and CO_2 in both developed and emerging economies (Kumazawa and Callaghan, 2010).

Since then the UNFCCC has introduced the Paris Agreement, a new legally binding international treaty to help tackle climate change, enforced in 2016, which has been signed by 186 countries. All parties share the same long-term goals, agreeing to a common clause to combat climate change. Developed countries are taking the lead on reducing emissions, whilst also providing financial assistance for less developed economies, to help assist with both mitigating and adapting to the reduction of CO_2 emissions (UNFCCC, 2015).

Specific help is given to developing economies as many experiences an increase in production and industrialisation when growing. These activities can involve high energy use, especially the use of oil, natural gas, and coal, all of which are non-renewable resources and produce high levels of CO_2 emissions (Bajželj *et al.*, 2013). Recent countries to have experienced an increasing economic growth is Brazil, Russia, India, China, and South Africa, given the acronym 'BRICS'. Figure 2 shows their increase in different forms of energy consumption since 1965, with China and India contributing the most to oil and coal consumption, and China and Russia being most responsible for natural gas consumption (BP, 2020).

Figure 2 : BRICS Combined Total Consumption (1965 – 2019)



The 'BRICs' were first established by Goldman Sachs in 2001 (South Africa introduced in 2010) as countries which were likely to shape the global economy in the next 50 years, with their rate of growth projected to surpassed that of the G7 countries (United States, Japan, United Kingdom, Germany, France, Italy, and Canada) (O'Neill, 2001). The BRIC economies are said to hold a larger percentage of world GDP than G7 countries by 2050, therefore set to experience rapid growth in the coming decades.

As previously stated, emerging, and developed countries are more likely to emit higher CO_2 emissions, and therefore it is important to understand the relationship between these dominant world economies and the environment. Whilst also giving insight into how impactful current international climate change agreements are in resolving global warming. This is especially important ahead of the 26th UNFCCC conference in Glasgow this year (2021), where countries are obliged to bring emission cutting targets (COP26, 2021).

This paper continues as follows. Section 2 focuses on the aims and objectives of the study, then section 3 goes on to analyse previous literature in this research area. Section 4 provides an analysis of the raw data set and outlines the theoretical backing and methodology that will be used. Whilst section 5 discusses the results, and section 6 gives the overall concluding remarks and evaluation of the study and process. Finally, sections 7 hold the final conclusion, followed by the references and appendix.

2. Aims and Objectives

The aim of this research is to investigate whether economic growth has an impact on CO_2 emissions in the BRICS and G7 countries, and if the Paris Agreement has been effective in respect to CO_2 emissions. To study this, the following five null hypotheses will need to be tested to see if they can be accepted or rejected, for each of the BRICS and G7 countries (each for real and per capita figures).

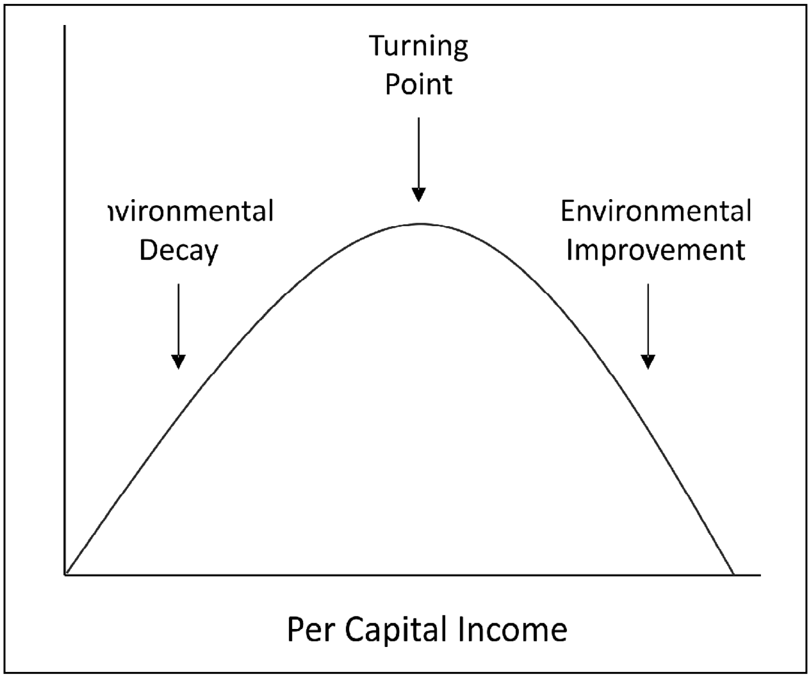
1. The relationship between GDP and CO_2 emissions follows an Environmental Kuznet Curve
2. There is a positive causality relationship between energy consumption and GDP
3. There is a positive causality relationship between energy consumption and CO_2 emissions
4. The signing of the Paris Agreement has caused a decrease in CO_2 emissions
5. BRICS and G7 economies have different income-energy-output nexuses

3. Literature Review

3.1. Theoretical Background

Previous literature on environmental economics make use of the Environmental Kuznet Curve (EKC) as a way of understanding the relationship between environmental deration and national income. Kuznet (1955) first acknowledged the relationship between per capita income and income inequality. Known as the Kuznet Curve (KC), the relationship is said to be displayed as a bell-shaped curve, suggesting that as per capita income increases so does income inequality, until a certain point, when income inequality will start to decrease as per capita income increases. Since then, the KC has become a means of analysing the relationship between environmental inequality and economic growth, known as the EKC. First hypothesised and examined by Grossman and Krueger (1991), the EKC states that as economic growth increases, pollution levels will increase, but will then begin to decrease after they reach a certain turning point, following an inverted U-shape relationship, as shown in figure 3.

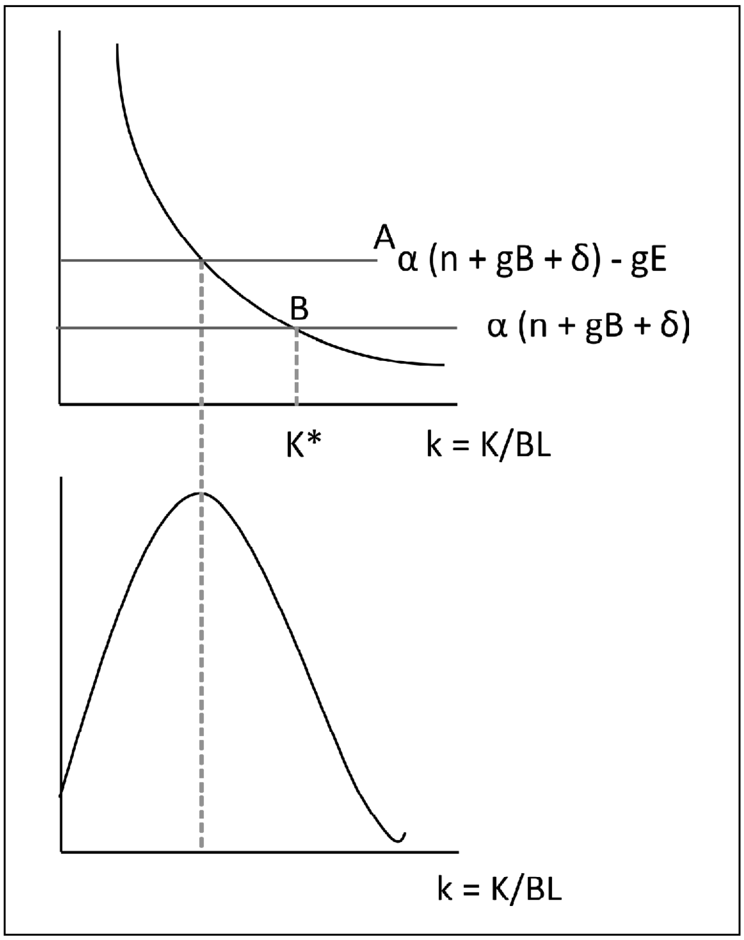
Figure 3 : Environmental Kuznet Curve



Solow (1956) developed the neo-classic growth model, suggesting economic growth comes from three components: capital, labour, and investment. Solow believed that economic growth will only increase momentarily from an increase in capital investment. The marginal product of any additional capital units will exhibit diminishing returns, and the economy will move back to a long-term growth path. This therefore suggests that in the short run, the economy will reach a constant rate of growth, reaching what is can be described as the 'steady state'. At this point, output per worker and capital per worker are constant. To improve upon this, Solow suggests an increase in technological change to help stain to long term growth. Differing rates of technological change will explain different countries variation in growth rates, if no exogenous factors, such as technological change, countries will move towards a stead state and continue a constant rate of growth thereafter. Therefore, suggesting the need to increase investment to counteract diminishing capital stock.

When introducing environmental degradation into this theoretical model, a study from Brock and Taylor (2010) identifies the 'Green Solow Model', including the EKC. The diminishing returns and technological progress identified by the Solow model are fundamental to the findings of the EKC, demonstrated in figure 4 (Brock and Taylor, 2010). In the early stages of development, diminishing returns of capital starts by prompting brisk economic growth. As a result of the rise in GDP, CO_2 emissions will increase. Once the economy starts to approach a more balance growth path, technological progress will lead to a decline in CO_2 emissions, tending towards net zero emissions, as described in EKC literature as an inverted U-shape relationship.

Figure 4 : Green Solow Model



3.2. Environmental Kuznet Curve Literature

Early literature from Grossman and Krueger (1991, 1995) studied the relationship between economic growth and the environment. In their 1991 paper, analysing the impact of the North American Free Trade Agreement, they found additional variables within their regression analysis such as trade liberalisation, alongside the traditional EKC variables, allows for wider explanation around the topic of economic growth and environmental quality (Grossman and Krueger, 1991).

Over the years many people have studied the environment income relationship, and since Grossman and Krueger's pioneering research, other authors have included additional variables when studying the environment-income nexus. Halicioglu (2009) included foreign trade and found a noticeable relationship between increased trade and a rise in CO_2 emissions in Turkey. Likewise, Zhang and Cheng (2009) used Granger causality to examine the relationship between urban population, environment, and income, finding a positive relationship between urbanisation and economic growth, energy consumption and carbon emissions in China in the long-run, but no immediate shocks (Zhang and Cheng, 2009).

3.3. Energy-output-income nexus literature

Alongside the environment income/growth relationship, previous research also focused on the energy-output nexus. Apergis and Payne (2009a) studied the relationship between energy consumption and economic growth using a panel data framework for 11 countries of the Commonwealth of Independent States from 1991 to 2005. They found a long-run bidirectional causality between real GDP and energy consumption (Apergis and Payne (2009).

Ang (2007) conducted the first paper to combine the nexus of output-energy and output-pollution by including energy consumption into the EKC equation, as shown below (Ang, 2007). Ang uses a multivariate vector error-correlation model to study France between 1960 and 2000. He does not include multiple countries within his model, as cross-sectional studies do not allow for the individuality of countries to be explored. The findings suggest that increased energy use results in higher CO_2 emissions, and CO_2 emissions and output have a quadratic relationship, mirroring previous findings of the EKC (Ang, 2007).

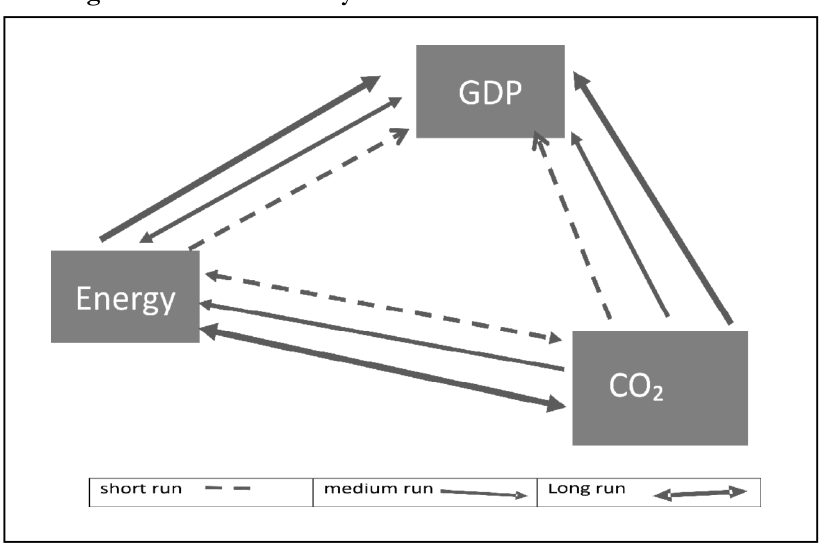
$$C_t = \beta_0 + \beta_1 E_t + \beta_2 G_t + \beta_3 G^2_t + \varepsilon_t$$

Ang's literature has been referenced by many, and since 2007, has been expanded to analyse other countries. Apergis and Payne (2010) developed upon their 2009 Commonwealth of Independent States research to include CO_2 emissions. They adapted the traditional EKC to include energy consumption. Using panel unit roots tests and panel cointegration tests for the 11 countries they found for there to be a long run equilibrium relationship between per capita measures of CO_2 emissions, GDP and energy consumption, with GDP and CO_2 emissions showing a quadratic relationship, similar to that of the EKC. They found that the increase in GDP was caused by an increasing consumption of energy, causing a by-product of CO_2 emissions (Apergis Payne, 2010). However, an important note to make is about their results for Russia, who show a short-run negative relationship between energy consumption and GDP, due to the excessive amount of energy being consumed, also known as the "Dutch" disease.

With reference to BRICS economies, Pao and Tsai (2010) also studied the relationship between CO_2 emissions, energy consumption and economic growth for the BRIC countries. Figure 5 from Pao and Tsai's study highlights the results from their panel causality test (Pao and Tsai, 2010, p.7857). Their findings suggest that there is a strong causality between energy consumption and CO_2 emissions, and a bidirectional long-run relationship between energy consumption and real output, but only a causality from energy consumption to output in the short-run and finding a strong negative relationship between CO_2 and output (Pao and Tsai, 2010). Alongside this, they discover the EKC hypothesis can only be accepted for three of the BRIC countries and rejected in India (Pao and Tsai, 2010).

Aligning with these findings, recent literature from Danish *et al.* (2019) studied the effects of GDP, natural resources, and renewable energy data on CO_2 between 1990 and 2015 for BRICS economies. Their research highlights the importance of ensuring cross-sectional dependence by using an augmented mean group (AMG)

Figure 5 : Panel Causality relations for BRIC & G7 countries



panel data estimation method, as they found a shock in one sample country may affect the other countries (Danish et al., 2019). They conclude that EKC exists in all BRICS countries besides India, which was found to be statistically insignificant (Danish *et al.,* 2019).

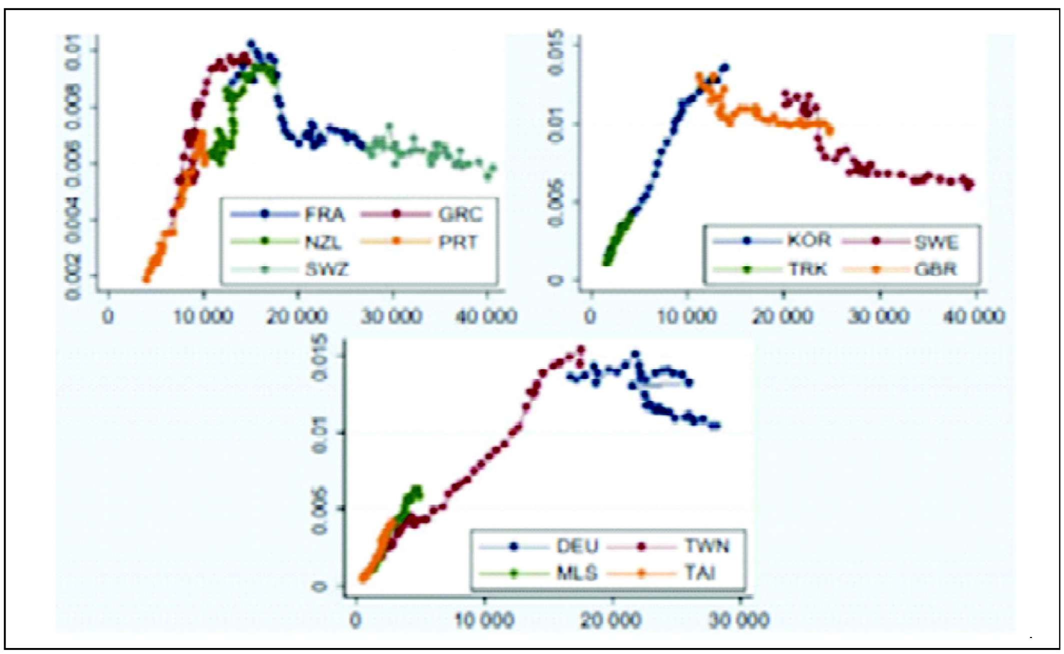
Chang (2015) applied a DEA-DFF model to analyse the G7 and BRICS countries room for improving their energy and emissions intensity and carbonisation value. They studied the 12 countries from 2000 to 2010, and found that before 2005, G7 countries had a larger room for improving their carbonisation value, however after 2005, this changed to the BRICS having more room for improvement (Chang, 2015). Alongside this, they find that the G7 and BRICS economies show an inverted U-shaped EKC, however did not have the shame inverted U-shape relationship for their other variables (Chang, 2015).

When examining economic growth, environmental pollutants, and energy consumption in the same framework, studies use a myriad of different methodologies to gain their results. From this literature review, we see that many use panel data frameworks or cross-sectional techniques, which show completely homogeneity. They do this through panel data regression models, panel unit root tests and panel cointegration tests, or causality tests (Pao and Tsai, 2010) (Apergis and Payne, 2009) (Apergis and Payne, 2010). A limitation of this is that all parameters are identical for all countries, meaning results for the EKC end up giving an identical result for all countries, therefore ignoring individual differences. Other research will only analyse one country at a time, using time series analysis to account for complete heterogeneity within their studies (Ang, 2007) (Halicioglu, 2009) (Zhang and Cheng, 2009). However, as mentioned in Danish et al (2019), this method ignores cross-sectional dependence and therefore allows for complete heterogeneity. Maddala *et al* (1997), noted that the choice between the two methods is difficult, noting that "the parameters are not exactly the same, but there is some similarity between them' (Maddala et al, 1997, pg. 91).

Jobert *et al* (2014) research analyses the two different methodological approaches that empirical literature takes when study the EKC, with a predominant focus on why allowing for heterogeneity when analysing the EKC is important. The authors investigated 55 countries from 1970 to 2008, using per capita CO2 emission as their dependent variable, and per capita GDP and energy consumption as their independent variables. They start by running an ordinary least-squared (OLS) regression and confirmed the existence of an EKC for their sample countries. However, this gave a 'world' EKC, as heterogeneity is ignored within this methodology framework. They went on to apply an Empirical Iterative Bayes' estimator to allow them to classify countries according to their individual EKC pattern. They found that depending on the country's development stage, the CO2-GDP relationship differed, with only Hong Kong, Denmark, Mexico, and Saudi Arabia showing a traditional inverted U-shape EKC. Figure 6 from their paper demonstrates that combining different countries on the same graph gives the illusion of an overall EKC, however in reality, each country has a different EKC relationship depending on their level of development (Jobert *et al.*, 2014). Their findings suggest that to account for heterogeneity when studying the EKC, panel data regression methods do not give enough in-depth analysis when studying individual countries CO2-GDP relationships.

Mazzanti and Musolesi (2013) compared homogeneous, heterogeneous and shrinkage/Bayesian estimators when researching the EKC for three different groups of countries. The heterogeneous estimation methods used include mean group (MG) and Swamy, and then CCEMG and AMG which are heterogenous estimators which allow for cross-sectional dependence. They found that there was consistency of

Figure 6 : Heterogenous Environmental Kuznet Curves



Note: Different trends in selected countries in CO2 emissions ('000 tonnes) in y-axis and per capita GDP constant 1992 US dollars in x-axis; source Jobert *et al.* (2014).

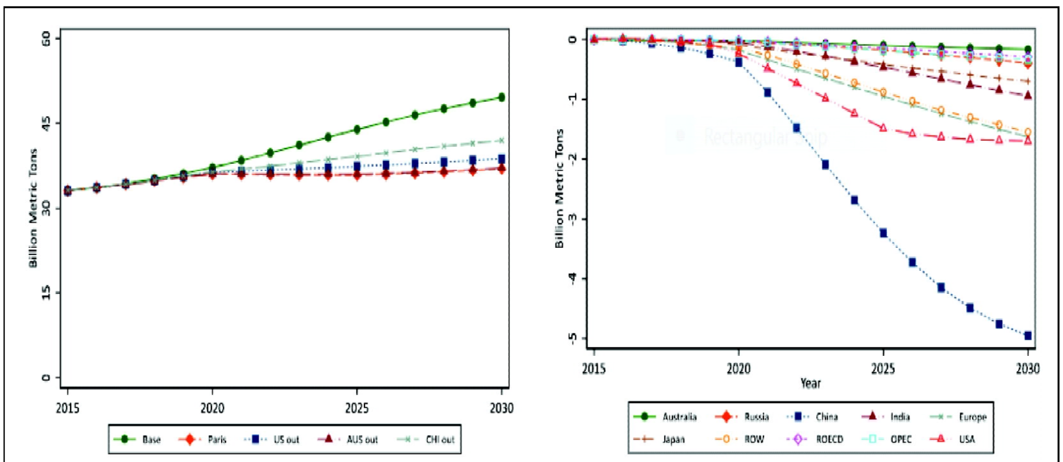
estimates across the different models, Bayesian or not, allowing them to draw clear conclusions on the existence of the EKC for different country groups.

3.4. Paris Agreement Literature

The second part of this study will assess the current success of the Paris Agreement for the G7 and BRICS countries. Currently, there is little econometric conclusions to be drawn from the Paris Agreement, however, there has been a myriad of literature looking at the potential end result of the Paris Agreement, and whether the UN is likely to achieve its objectives.

Liu *et al* (2020) conducted a study estimating future CO_2 emissions if countries do and do not reach their Paris Agreement targets base on what they are currently achieving, alongside the effects of countries withdrawing from the agreement, in light of the, then, current Trump administration withdrawing the US from the Paris Agreement. Figure 7 taken from their findings highlights the importance of the Paris Agreement, and also the importance of particular countries participation within the agreement (Liu *et al.,* 2020, p.7). The first graph highlights the outcomes if a particular country were to drop out of the agreement. The most detrimental departure would be from China, as almost half the reduction in global emissions is predicted to come from China's participation, showing how vital their involvement is to the

Figure 7 : Paris Agreement CO2 emissions predictions



Global CO_2 emissions levels under Paris and other scenarios.

Change in CO_2 emissions under Paris relative to BAU.

Source: Liu, W., McKibbin, W.J., Morris, A.C. and Wilcoxen, P.J., 2020. Global economic and environmental outcomes of the Paris Agreement. *Energy Economics*, *90*, p. 104838 outcome of the agreement. Following on from this, the second graph further emphasises China's position, as they find that by 2030, the largest reduction in CO_2 emissions will be from China, followed by the US (Liu *et al.,* 2020).

Furthermore, there has been a lot of statistical analysis on previous UN climate change agreements, such as the Kyoto Protocol. A study conducted by Kumazawa and Callaghan (2010) introduced the analysis of the Kyoto Protocol climate change agreement alongside the EKC. They do this by studying the impact of world CO_2 emissions for 177 countries (grouped into Annex B or non-Annex B countries) for the years 1980 to 2006. To analyse this, they ran an unbalanced panel data Chow test to jointly test for two structural breaks. The first being the years leading up to the signing of the protocol (1998 to 2004) and then when the protocol was enforced (2005), they denote these using dummy variables. To account for unobserved heterogeneity, they conducted a Hausman test to determine the use of a random effects model. They found that for Annex-B countries, CO2 emissions decreased, especially after the enforcement of the Kyoto Protocol, whereas Non-Annex B countries experienced no change. However, they did find that for both groups, industrial production contributed to a reduction in emissions in the first period, whilst in the second period it only further decreased for non-Annex B countries. This finding may suggest that developing countries are playing an indirect role in the reduction process through cross-board transfers of emissions credits (Kumazawa and Callaghan, 2010).

As well as this, Kumazawa and Callaghan also used the estimated coefficients from the unbalanced panel regression to test for their augmented EKC model. They expanded the traditional EKC to include industrial production as a percentage of GDP as an additional variable, noting that they did not include any additional control variables to ensure the results remained robust for the EKC (Harbaugh *et al.*, 2002). The estimated coefficients from their regression indicated that the two groups have different patterns in their carbon emissions. This was in line with their expectations, as the non-Annex B countries are not bounded by CO2 reduction targets and therefore these countries experienced an increase in emissions from an increase in income, describing an exponential EKC. Whereas the Annex B countries experienced a reduction in emissions from an increase in GDP, showing an inverted-U shaped EKC.

The findings of their study show the effective of the protocol for reducing emissions in developed countries and highlights the potential need for targets in

Table 1 : Summary of EKC literature methodology and findings

Author/s	Countries	Methodology	Findings
Halicioglu (2009)	Turkey	Variables: output-energy-pollution-foreign trade nexus. Method: Cointegration procedure Granger causality	Cointegration procedure & Granger causality: Long run relationship between all variables
Zhang and Cheng (2009)	China	Variables: output-pollution-urban population nexus. Method: Granger causality	Long run relationship between all variables
Ang (2007)	France	Variables: Output-energy-pollution nexus. Method: Panel unit root tests, Panel cointegration tests and Granger causality test	Panel unit root tests: all variables non-stationary, first difference is stationary. Panel cointegration test: long run relationship is present Granger causality test: Short run: $\Delta E \rightarrow \Delta G, \Delta G^2$ Long run: $\Delta G, \Delta G^2 \rightarrow \Delta C, \Delta E$
Apergis and Payne (2009, 2010)	Commonwealth of independent states	Variables: Output-energy nexus (2009) Output-energy-pollution nexus (2010). Method: Panel unit root tests, Panel cointegration tests and Granger causality test	↑ energy consumption → ↑ GDP By product: ↑ CO2 emissions (Quadratic Relationship between GDP & CO2) Granger causality test: Short run: $\Delta E \rightarrow \Delta C$ Long run: $\Delta G, \Delta G^2 \rightarrow \Delta C$
Pao and Tsai (2010)	BRIC	Variables: Output-energy-pollution nexus. Method: Panel unit root tests, Panel cointegration tests and Causality test	Panel unit root tests: all variables non-stationary, first difference is stationary. Panel cointegration test: long run relationship is present EKC for Brazil, Russia, China, and South Africa
Danish et al (2019)	BRICS	Variables: Output-energy-pollution nexus. Method: Test for cross-sectional dependence and AMG panel data estimations	Test for cross-sectional dependence: Found cross sectional dependence EKC for Brazil, Russia, China, and South Africa
Jobert et al (2014)	55 countries	Variables: Output-energy-pollution nexus. Method: Panel data regression and shrinkage approach	Panel Data Regression: World EKC Shrinkage approach: Gives individual EKC relationships for each country.
Kumazawa and Callaghan (2010)	177 countries (Grouped into developed and undeveloped countries)	Variables: Output-energy-pollution nexus. Method: Panel Regression Analysis with a Chow Test using dummy variables for before and after Kyoto Protocol	EKC accepted for developed economies, Kyoto Protocol reduced emissions. EKC rejected for developing economies

developed economies. However, this study only analysing the short-term effects, as the availability of data after the signing (one year) does not reflect long-term trends. Therefore, I will need to ensure a more appropriate number of years after the signing of the Paris Agreement to ensure my results hold substance.

Developing upon Pao and Tsai (2010) research, I would like to further their findings by using updated data, including South Africa, and comparing their relationship to that of more developed economies (G7). To do this I will be using a similar Chow-test to what has been used in Kumazawa and Callaghan (2010) to help gain an understanding of how impactful the implementation of the Paris Agreement has been on reducing their CO2 emissions since 2016 for the G7 and BRICS countries. I will also examine the relationship between CO2 emissions, energy consumption and economic growth by using panel data regression model to examine the existence of the EKC. In addition, this study will implement an augmented mean group estimation method, similar to that outlined in Danish *et al.* (2019), allowing for heterogeneity, whilst also accounting for cross-sectional dependencies between developed (G7 countries) and developing countries (BRICS).

4. Methodology

4.1. Data

This research will use annual data for BRICS and G7 countries on their CO2 emissions, GDP, and energy consumption over the period of 1990 to 2019. The selected time samples are consistent with the available data. CO2 emissions (million tonnes of carbon dioxide), primary energy consumption (exajoules) and per capita primary energy consumption (gigajoules) are collected from the BP statistical review of world energy (BP, 2020). CO2 emissions per capita is derived from dividing the real figures from country population figures collected from the World Bank world development indicators, as well as GDP and per capita GDP at constant 2010 US$ (World Bank, 2020).

Table 2 provides a statistical summary of the actual data values before taking the natural logarithm of the three variables for each country. The highest mean of CO2 emissions is from China (5,867.43) closely followed by the US (5,375.74), who also have the highest mean energy consumption (91.306) and real GDP (127,065). Meanwhile, the lowest mean of CO2 emissions is in Brazil (343.50) whereas the lowest mean for energy consumption (4.620) and real GDP (2,385) are in South Africa. Alongside this, China display the largest variation in CO2 emissions (508.21), energy consumption (7.172) and real GDP (8,467) found by the standard deviation. The smallest variation in CO2 emissions (5.45) and energy consumption (0.100) is in France, however the lowest variation in real GDP is in South Africa (190).

Table 2 - Descriptive statistics of initial data (before taking logarithm)

	CO2 emissions		Energy Consumption		Real GDP	
	Mean	S.D	Mean	S.D	Mean	S.D
Brazil	343.50	16.57	9.136	0.427	12,581	1,355
Russian Federation	1,592.16	38.91	28.532	0.511	9,856	1,240
India	1,349.67	110.03	18.401	1.476	11,231	1,543
China	5,867.43	508.21	76.576	7.172	45,948	8,467
South Africa	410.64	10.49	4.620	0.110	2,385	190
US	5,375.74	56.95	91.306	0.835	127,065	8,445
United Kingdom	530.80	11.76	8.999	0.113	21,391	1,272
France	356.76	5.45	10.444	0.100	20,714	1,130
Germany	835.03	13.63	14.035	0.097	28,680	1,350
Italy	397.08	8.29	7.031	0.093	16,770	811
Japan	1,208.79	11.28	20.549	0.245	47,400	1,203
Canada	513.35	7.91	12.812	0.197	11,412	897

CO2 emissions (million tonnes of carbon dioxide); per capita primary energy consumption (gigajoules) are collected from the BP statistical review of world energy (BP, 2020)

Figures 9, 10 and 11 below demonstrates the trends of each of the three variables over time for the different country groupings. All three variables have seen an increase from 1990 to 2019, with a fall in 2008, after the global financial crisis. GDP has

Figure 9

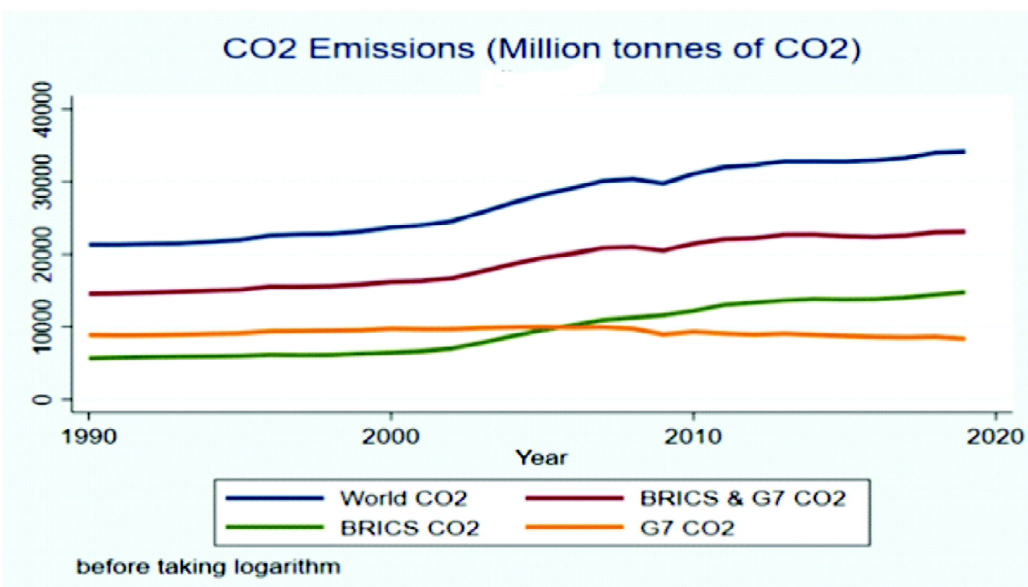


Figure 10

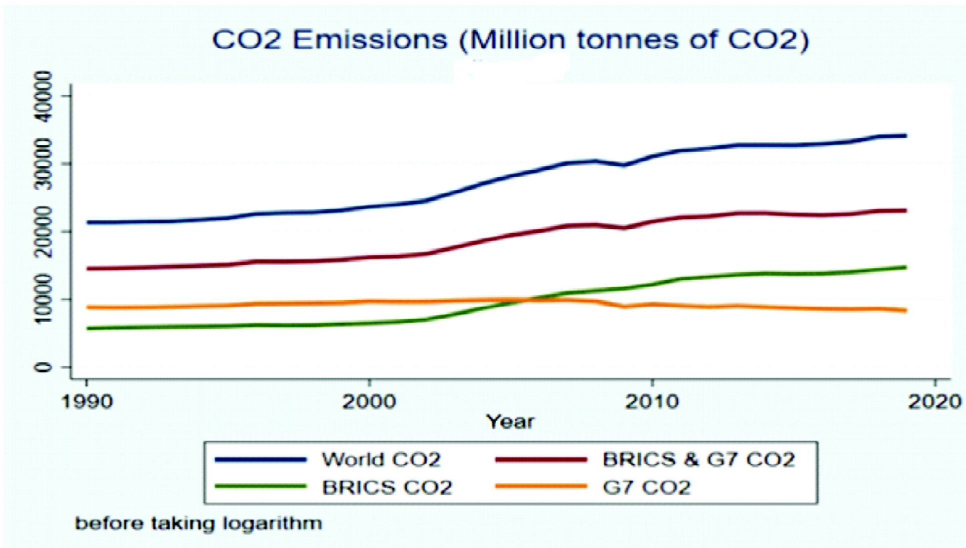
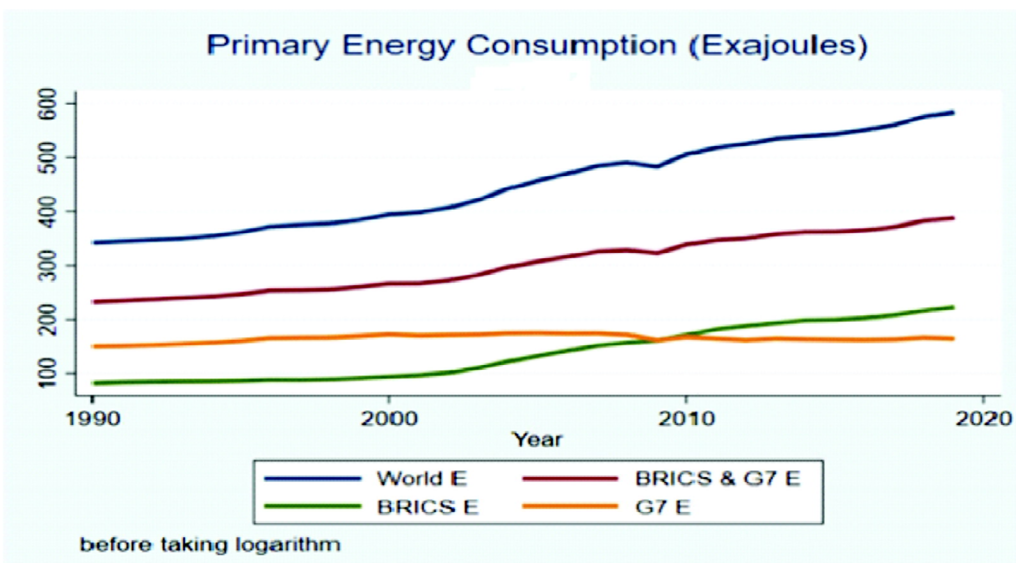


Figure 11



increased for both the BRICS and G7 countries, forming a similar trend to that illustrated of world GDP. CO_2 emissions and energy consumption are both seen to be increasing in G7 countries, whist BRICS countries see an increase. BRICS incline in CO2 and energy consumption has caused them to overtake the G7 countries, leading to them having higher energy consumption and emitting more CO2 emission.

These trends are also observable in table 2. BRICS percentage of world CO2 emissions has increased since 1990 from 26.63% to 43.19% in 2019. However, the opposite has happened in the G7 countries, with their percentage decreasing from 41.56% to 24.41% in 2019. This same trend occurs for energy consumption, where we see BRICS countries increase their energy consumption from 24.00% in 1990 to

Table 3 - Variables percentage share of world

	World	BRICS & G7	BRICS	G7
GDP				
1990	379,859.82	267,451.70	41,642.30	225,809.40
% Share of world		70.41%	10.96%	59.45%
2000	499,489.79	346,608.64	58,628.15	287,980.49
% Share of world		69.39%	11.74%	57.65%
2010	661,259.19	448,257.59	118,719.18	329,538.41
% Share of world		67.79%	17.95%	49.83%
2019	848,653.59	574,569.41	190,175.08	384,394.33
% Share of world		67.70%	22.41%	45.29%
% chance since 1990	123.41%	114.83%	356.69%	70.23%
CO2 emissions				
1990	21,331.50	14,546.54	5,680.82	8,865.72
% Share of world		68.19%	26.63%	41.56%
2000	23,676.45	16,182.71	6,446.02	9,736.69
% Share of world		68.35%	27.23%	41.12%
2010	31,085.53	21,458.94	12,171.26	9,287.68
% Share of world		69.03%	39.15%	29.88%
2019	34,169.00	23,098.31	14,758.84	8,339.47
% Share of world		67.60%	43.19%	24.41%
% chance since 1990	60.18%	58.79%	159.80%	-5.94%
Primary Energy Consumption				
1990	342.23	232.46	82.14	150.32
% Share of world		67.93%	24.00%	43.92%
2000	394.50	266.37	93.94	172.43
% Share of world		67.52%	23.81%	43.71%
2010	506.02	338.79	171.10	167.69
% Share of world		66.95%	33.81%	33.14%
2019	583.90	387.94	223.37	164.57
% Share of world		66.44%	38.25%	28.18%
% chance since 1990	70.62%	66.88%	171.93%	9.48%

38.25% 2019 as a percentage of world energy consumption, with an overall increase of 171.93% from 1990 to 2019 in real terms. For G7 countries we see of decrease from 43.92% in 1990 to 28.18% in 2019, only increasing 9.48% overall in real terms. When combining G7 and BRICS CO_2 emissions and energy consumption, their percentage of world share remains almost constant from 1990 to 2019, potentially down to the decrease in G7 and increase in BRICS economies levelling one another out.

From the preliminary data analysis, we can begin to sense the illusion of an EKC for the G7 and BRICS economies. The BRICS economies are seen as developing from their increase in GDP, alongside this we also begin to see an increase in their energy consumption and CO_2 emissions. Whereas the G7 countries which are considered developed, are experiencing less rapid growth, and a decrease in CO_2 emissions and primary energy consumption as a percentage of world share.

4.2. Model

Building off previous literature, Grossman and Kruger (1995) noted the need for extra variables is necessary for analysing the relationship between economic growth and CO_2 emissions. I will therefore also be including energy consumption, following the empirical literature from Ang (2007), the first to analyse the linear quadratic equation showing CO_2 emissions as a function of GDP and energy consumption. Alongside this I was also include dummy variables as outlined in Kumazawa and Callaghan (2010) to be able to observe how the Paris Agreement has impacted CO_2 emissions.

Equation (1) will use real figures, while equation (2) will use per capita figures. Both of these equations will be analysed in this study to understand the relationship between economic growth and environmental degradation, with the first considering real country figures, and the second equation accounting for country population to understand if these produce different outcomes.

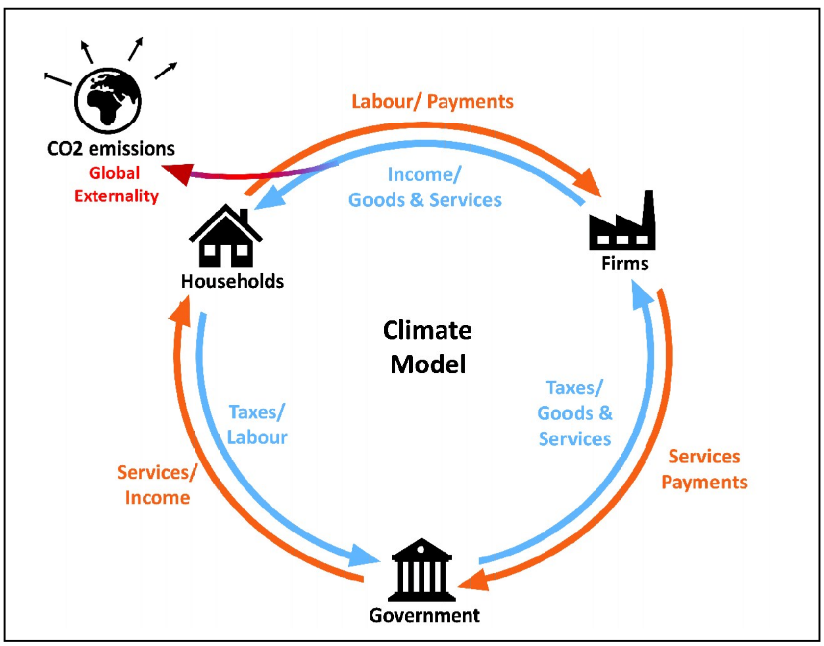
$$\begin{aligned}\ln(C_{it}) = \beta_0 + \beta_1 \ln(Y_{it}) + \beta_2(\ln(Y_{it}))^2 + \gamma_0 \ln(E_{it}) + \gamma_1(\ln(E_{it}))^2 + \theta_0 A_t \\ + \theta_1 A_t \ln(Y_{it}) + \theta_2 A_t(\ln(Y_{it}))^2 + \theta_3 A_t \ln(E_{it}) + \theta_4 A_t(\ln(E_{it}))^2 + \varepsilon_{it}\end{aligned} \quad (1)$$

$$\begin{aligned}\ln(CPC_{it}) = \beta_0 + \beta_1 \ln(YPC_{it}) + \beta_2(\ln(YPC_{it}))^2 + \gamma_0 \ln(E_{it}) + \gamma_1(\ln(E_{it}))^2 + \theta_0 A_t + \\ \theta_1 A_t \ln(YPC_{it}) + \theta_2 A_t(\ln(YPC_{it}))^2 + \theta_3 A_t \ln(E_{it}) + \theta_4 A_t(\ln(E_{it}))^2 + \varepsilon_{it}\end{aligned} \quad (2)$$

The dependent variable in this research (C_{it}) is the natural logarithm of CO_2 emissions, where (i) denotes the country and (t) denotes the year. CO_2 emissions are hypothesized to be influenced by the independent variables; GDP (Y_{it}) and energy consumption (E_{it}), both in a natural logarithm form. Additionally, the square root is taken of each of these variables and is included in the model, allowing for nonlinearity in the parameters. Equation (2) is structured the same way, with all figures in per capita terms. A_t signifies the dummy variable used to identify the signing of the Paris agreement to study its effectiveness so far.

All the variables are given in the form of a natural logarithm, meaning the parameters β_0, β_1, β_2, γ_0 and γ_1 represent the long-run elasticity estimates of CO_2 emissions with respect to GDP, GDP-squared, energy consumption and energy consumption squared. Alongside this, the data series can be interpreted in growth terms once the first difference is taken. In previous studies the signs of these parameters have varied based off whether they are researching developed or developing economies. For example, in developed countries, Kumazawa and Callaghan (2010) find GDP per capita to be negative, and GDP-squared to be positive, whereas for developing economies, they find both to be positive (Kumazawa and Callaghan, 2010).

Figure 8: Climate Model



4.3. Conceptual analysis

Derived from the Mundell-Fleming model (Fleming, 1962) (Mundell, 1963), figure 8 has been modified to illustrate the connection between CO_2 emissions in a small open economy. The EKC states that CO_2 is a function of GDP which is derived from all domestic production. An individual's utility function is denoted as a function of consumption of goods and services; however, CO_2 is a by-product of this. Humanity is yet to connect the correlation between human's activities and the increasing rate of emissions. In economics, this would be considered as a market failure, as society bears the costs of global warming. This therefore suggests, that as GDP increases year on year from an increase in production, CO_2 emissions will also increase.

$$Y_{it} < Y_{it+1} < Y_{it+2} < \dots\ Y_{it+T}$$

$$\therefore\ CO_{2it} < CO_{2it+1} < CO_{2it+2} < \dots\ CO_{2it+T}$$

The polluters pay principle from the 1992 Rio Declaration could be applied to firms through the use of a carbon price. This can be done in multiple ways, either through a carbon tax or through a quote system, in which companies will have a limit to the level of emissions they can produce in a certain, allowing for flexibility through firms being able to 'trade' their limits, as some industries are more polluting than other, whilst the maximum for the period nationally/globally would not be exceeded. The World Bank estimated the appropriate carbon will be consistent across the world, suggesting an appropriate price would be \$40-80/tCO_2e by 2020, and US\$50-100/tCO_2e by 2030, for countries to be able to successfully meet their Paris Agreement goals (World Bank, 2017). However, further research found that a carbon price was hard to implement due to societies aversion to taxes (Bassi *et al.*, 2017).

Therefore, it may be appropriate to limit the extent of economic growth that allows for a minimum amount of CO_2 emissions, based off the EKC quadratic function as shown below:

$$Min\ CO_2 = \beta_0 + \beta_1 Y_{it} + \beta_2 Y_{it}^{\ 2}$$

To find the optimal GDP level for each country, the following equation must be completed

$$\frac{\partial CO_2}{\partial Y_{it}} = \beta_1 + \beta_2 Y_{it} 2 = 0$$

$$Y_{it} = \frac{-\beta_1}{2\beta_2} \tag{3}$$

4.4. Econometric Method

To test for each of the null hypotheseses, the method will be broken down into five sections, each giving way to answering the null hypotheses.

As previously shown in the literature review, many studies use panel data techniques to understand the environment-energy-income nexus. Therefore, this study will use a panel approach in which the cross-sections are BRICS and G7 countries, and the time series are balanced for all countries, between the periods of 1990 to 2019.

Jobert *et al.* (2014) highlighted the need to show both global (or grouped) EKC information, as well as country-specific information to be able to critically assess each countries CO_2 emissions and their individual countries areas for improvement. This will be especially important within this study to help assess the current successfulness of the Paris Agreement; therefore, this methodology main focus will be on heterogeneous estimation methods.

4.4.1. Preliminary Analysis

To analyse the 'grouped' EKC relationship, this study will first report the preliminary findings of a fixed and random effects regression model. Fixed effects models are used for when unobserved heterogeneity between countries does not change over time, whereas random effects models are most appropriate when unobserved heterogeneity is randomly distributed. The Hausman specification test will be used to account for unobserved heterogeneity, by formally identifying whether a fixed or random effects model is most appropriate (Hausman, 1978). If the Hausman test indicates that a random effects model is most appropriate for this data, a Breusch and Pagan Lagrangian Multiplier test will then be conducted, to see if it's most appropriate to use a random-effects or a pooled OLS regression analysis. If the Hausman test suggests the use of a fixed effects test, I will not need to proceed with a Breusch and Pagan LM test (Breusch & Pagan, 1980).

Cross-sectional dependence

Panel data models are likely to exhibit cross-sectional dependence (CD) in the errors, arising from the presence of increased globalisation, causing stronger interdependence between countries. If the common factors are unobserved and uncorrelated, then a fixed-effects or random-effects estimation method will be consistent. However, if common factors are unobserved and correlated, then these models will not be appropriate. Therefore, CD will need to be examined to understand if it needs to be accounted for in heterogenous estimators. In-line with other empirical literature, this research will use a Pesaran test for CD, outlined in Pesaran (2004).

4.4.2. Augmented Mean Group Estimator

With heterogeneity at the forefront of recent EKC literature (Jobert e*t al.*, 2014), this study will be employing an augmented mean group (AMG) regression developed by (Bond & Eberhardt, 2009) (Eberhardt & Teal, 2010) as the main econometric estimation model. It is commonly used and a well-regarded estimation technique in EKC literature (Danish *et al.*, 2019). This particular model allows for CD by implementing a common dynamic effect parameter, however, is predominantly a heterogeneous estimator and will therefore allow for individual differences to also be recognised.

Wager (2008) noted that for series of per capita GDP and per capita CO_2 emissions data is often non-stationary. A lot of previous studies in this research area conduct panel unit root tests when analysing multiple countries (Ang, 200) (Apergis and Payne, 2009, 2010) (Pao and Tsai, 2010). These studies all find that CO2, GDP, GDP^2, E are all non-stationary in their levels, however, are stationary when taking the first difference. However, Jobert *et al.* (2014) highlight that many unit root tests developed for panel data have been replicated from time-series unit root tests, meaning that even when rejecting the null hypothesis (no unit root), it does not mean all variables are stationary. An AMG estimation method is able to account for non-stationary data, and therefore this study will overcome the limitations associated with unit root tests for panel data.

Other similar estimation methods include mean group (MG) (Pesaran & Smith, 1995) and pooled mean group (PMG) (Pesaran *et al.*, 1999). PMG analyses both the short and long-run equilibrium, however only accounts for heterogeneity in the short-run and ignores CD. The PMG long-run estimations are homogenous, given by the error-correcting speed, therefore assuming slope coefficients to be identical. MG only analyses the long-run, however accounts for complete heterogeneity, not considering that certain parameters will have similarities across countries. AMG overcomes a lot of these issues by using a cross-group average of the evolution of the unobservable time-invariant fixed effects (FTP), which is known as the common dynamic process, something that MG ignores. This means AMG addresses slope heterogeneity, TFP for each intercept and group-specific model parameters are averaged across the panel.

4.4.3. Panel cointegration

Once this has been done, panel cointegration tests will be used to assess for the presence of a long-run relationship between CO_2 and the explanatory variables; GDP and energy consumption, as shown in many other studies (Ang, 2007) (Apergis and Payne, 2009, 2010) (Pao and Tsai, 2010). This study will employ a Kao (1999) modified Dicky-Fuller test, and the Pedroni (2004) modified Phillips-Perron test. However, Jobert *et al.* (2014) noted that panel cointegration tests do not take heterogeneity into account, meaning the coefficients are assumed to be identical for all countries, something this study will consider when drawing conclusions on the final outcomes.

4.4.4. Granger causality

Panel AMG estimates and cointegration tests do not consider the direction of causality among variables. As a result, this study will apply a postestimation Panel VAR-Granger causality Wald test (Granger, 1969), as shown in Pao and Tsai (2010). The particular Granger causality method first applies a panel VAR model by lagging each variable, and performing a multivariate panel regression, estimated by a GMM estimation model.

4.4.5. Paris Agreement

To analyse the current successfulness of the Paris agreement a dummy variable will be added into the regression analysis (A_t). The sign of the parameter will be used to examine whether there has been a decline in CO_2 emissions since the enactment of the Paris Agreement for each individual country, with the overall panel parameter representing the overall percentage change in CO_2 emissions year on year since the ratification of the agreement for the cross-sections as a whole.

5. Empirical Results and hypothesis findings

5.1. Preliminary findings

For both real and per capita figures, the Hausman specification test could not be rejected, indicating that the appropriate model for the preliminary findings is the random-effects model, over the fixed-effect model. The results from the Breusch and

Pagan LM test also indicated that the most appropriate model is a random effect over a pooled OLS. Therefore, we will proceed with a random-effects panel data regression.

The results for real figures show lnY to be positive and statistically significant, and lnYsq to be negative and statistically significant, both at the 5 percent level. These findings suggest the presence of an EKC when all 12 countries are included in the panel. Alongside this, the lnE is also positive and statistically significant, suggesting a strong linear relationship with CO_2 emissions.

However, when analysing the per capita figures, the same results are not found. Instead of an inverted U-shape relationship between lnYpc and lnCpc, the results indicate a downwards sloping linear relationship. Neither find a statistically significant relationship for energy consumption squared, implying that there is not a quadratic relationship.

To test for CD, the Pesaran (2004) was conducted. For both real and per capita figures, the null hypothesis could be rejected, suggesting there is CD across the G7 and BRICS economies in this panel.

Table 4 - Panel Regression Results

Variables	Real figures (1)			Per capita figures (2)		
	Fixed-effects	Random-effects	OLS	Fixed-effects	Random-effects	OLS
Dependent Variable	lnC	lnC	lnC	lnCpc	lnCpc	lnCpc
lnY | lnYpc	0.636**	0.620**	-4.067***	-0.212*	-0.202***	-2.556***
	(0.314)	(0.313)	(0.793)	(0.111)	(0.109)	(0.247)
lnYsq | lnYpcsq	-0.14**	-0.014**	0.069***	0.003	0.003	0.123***
	(0.006)	(0.006)	(0.014)	(0.006)	(0.006)	(0.013)
lnE | lnEpc	1.234***	1.233***	1.012***	1.286***	1.292***	3.176***
	(0.047)	(0.047)	(0.125)	(0.101)	(0.101)	(0.192)
lnEsq | lnEpcsq	-0.005	-0.005	0.0227	-0.011	-0.012	-0.214***
	(0.007)	(0.007)	(0.021)	(0.010)	(0.01)	(0.019)
At	-0.027***	-0.027***	-0.030***	-0.026***	-0.026***	-0.022
	(0.006)	(0.006)	(0.035)	(0.007)	(0.007)	(0.033)
_cons	-3.336	-3.098	63.70735	-4.540***	-4.587***	2.478***
	(4.380)	(4.364)	(11.063)	(0.326)	(0.331)	(0.810)
prob > F	0.000		0.000	0.000		0.000
prob > chi2		0.000			0.000	
R-squared	0.9286	0.9288	0.9462	0.9126	0.9128	0.9344
Hausman Test		0.9065			0.3635	
Breusch & Pagan LM Test			0.000			0.000
N	12	12	12	12	12	12
T	30	30	30	30	30	30
N x T	360	360	360	360	360	360

Standard error below coefficients in parentheses

N = number of cross-sectional observation

T = number of years

***p<0.01 **p<0.05 *p<0.1

5.2. Augmented Mean Group

For parameter estimation, this study uses AMG to analyse the effects of GDP, GDP^2, energy consumption, and energy consumption squared. For real level figures, the results can be found in table 5.

The natural logarithm of GDP and GDP^2 is positive and negative, respectively, for Brazil, China, South Africa, the United States, Japan, and Canada, all significant

Table 5 - Real figures AMG estimator Results

Countries	Real level figures - AMG estimator							
	lnYpc	lnYsq	lnEpc	lnEsq	At	_cons	EKC	CO_2 after PA
BRICS	12.909 (9.983)	-0.234 (0.179)	-0.660 (0.594)	0.418 (0.161)***	-0.003 (0.014)	-172.283 (139.254)	X	X
Brazil	51.722 (25.220)**	-0.928 (0.449)**	-2.016 (1.407)	0.870 (0.345)**	-0.056 (0.019)***	-714.306 (353.017)**	√	↓
Russia	-2.963 (2.019)	0.053 (0.0363)	-1.765 (1.190)	0.427 (0.174)**	-0.006 (0.005)	50.268 (28.195)*	X	X
India	-0.016 (3.886)	-0.001 (0.070)	1.110 (0.560)*	0.014 (0.104)	0.015 (0.011)	5.287 (52.963)	X	X
China	4.932 (1.395)***	-0.088 (0.025)***	0.247 (0.0514)	0.118 (0.064)*	0.024 (0.012)*	-63.156 (18.841)***	√	↑
South Africa	10.872 (5.515)**	-0.203 (0.104)**	-0.874 (0.829)	0.660 (0.267)**	0.010 (0.007)	-139.509 (72.645)*	√	X
G7	-5.996 (9.026)	0.105 (0.157)	6.270 (3.595)*	-0.946 (0.747)	-0.129 (0.016)***	82.410 (127.974)	X	↓
United States	13.713 (7.128)*	-0.229 (0.118)*	2.191 (7.588)	-0.096 (0.838)	-0.137 (0.009)***	-204.419 (96.947)**	√	↓
United Kingdom	-30.858 (0.543)***	0.543 (0.161)***	17.149 (3.768)***	-3.646 (0.859)***	-0.212 (0.013)***	424.572 (129.369)***	X	↓
France	-10.706 (32.920)	0.183 (0.578)	-3.12 (8.206)	0.936 (1.743)	-0.088 (0.018)***	164.439 (467.587)	X	↓
Germany	-37.129 (18.358)**	0.640 (0.319)**	15.468 (11.674)	-2.753 (2.218)	-0.129 (0.015)***	523.922 (256.657)**	X	↓
Italy	-14.048 (53.722)	0.240 (0.949)	-0.953 (4.085)	0.662 (1.051)	-0.102 (9.15)***	210.646 (758.980)	X	↓
Japan	9.703 (102.671)	-0.154 (1.751)	16.130 (14.004)	-2.601 (2.308)	-0.146 (0.022)***	-170.158 (1493.524)	X	↓
Canada	27.350 (14.111)*	-0.492 (0.253)*	-2.977 (5.596)	0.873 (1.124)	-0.090 (0.018)***	-372.133 (192.025)*	√	↓
Panel	-7.125 (9.891)	0.125 (0.174)	1.253 (3.225)	-0.173 (0.589)	-0.002 (0.010)	106.824 (137.990)	X	X

Standard error below coefficients in parentheses
***p<0.01 **p<0.05 *p<0.1

at the 10 percent (at least) apart from Japan which was not found to be statistically significant. These findings show an inverted U-shape for these countries, suggesting that growth in income initially causes an increase in CO_2 emissions, until a certain turning point, where the growth in income causes a decrease in CO_2 emissions, proposing the presence of an EKC. On the other hand, the remaining countries (Russia, the United Kingdom, France, Germany, and Italy) demonstrate a U-shape relationship, due to the sign of GDP and GDP^2 being negative and positive, respectively. However, many of these are statistically insignificant, apart from the United Kingdom and Germany, which are both significant at the 1 percent and 5 percent level, respectively.

Consistent with other empirical literature results, India, China, the United states, the United Kingdom, France, Italy, and Canada find a positive relationship between energy consumption and CO_2 emissions, with only the United Kingdom and India being statistically significant. Suggesting that an increase in energy consumption correlates with an increase in CO_2 emissions. The United Kingdom is also the only country to find a quadratic inverted U-shape relationship between these two variables, all other countries showed a statistically insignificant quadratic relationship.

Table 6 shows the AMG results for the per capita figures. Similar to the real figure findings, the only countries to demonstrate an EKC relationship are Brazil, China, the United States, Japan, and Canada, with Japan's findings not being statistically significant. Russia, the United Kingdom and Germany, all demonstrate a statistically significant quadratic U-shape EKC for per capita GDP, GDP^2 and CO_2 emissions.

Similar to other studies, per capita figures demonstrate more statistically significant results (Danish *et al.*, 2019). The United States, the United Kingdom and Germany are the only countries to show a statistically significant positive figure for the log of energy consumption. The same three countries all having a significant negative log of energy consumption squared, demonstrating an inverted U-shape relationship between energy consumption and CO_2 emissions. Whilst Brazil and Russia show a U-shape relationship between these variables. The relationships differed between BRICS and G7 countries, suggesting that the two may demonstrate relationship patterns between per capita energy consumption and CO_2 emissions.

5.3. Panel Cointegration

Table 7 shows both the Kao (1999) and Pedroni (2004) panel cointegration tests strongly rejects the null hypothesis of no cointegration for all tests at the 1 percent

Table 6 - Per Capita AMG estimator Results

Countries	Per Capita - AMG estimator							
	lnYpc	lnYpcsq	lnEpc	lnEpcsq	At	_cons	EKC	CO_2 after PA
BRICS	4.077 (5.437)	-0.228 (0.304)	-4.861 (2.465)**	0.711 (0.299)**	0.002 (0.013)	-10.901 (23.877)	X	X
Brazil	25.543 (14.312)*	-1.425 (0.784)*	-9.873 (3.990)**	1.503 (0.528)***	-0.045 (0.019)**	-100.432 (58.292)*	√	↓
Russia	-2.031 (0.610)***	0.109 (0.034)***	-4.210 (1.841)**	0.513 (0.173)***	-0.004 (0.005)	17.475 (5.383)***	X	X
India	-0.422 (1.367)	0.024 (0.100)	1.057 (0.929)	0.029 (0.175)	0.010 (0.012)	3.496 (3.482)	X	X
China	1.282 (0.332)***	-0.094 (0.022)***	-0.171 (0.476)	0.182 (0.063)***	0.025 (0.011)**	-7.286 (0.431)***	√	↑
South Africa	-3.988 (5.113)	0.242 (0.291)	-11.106 (11.010)	1.327 (1.202)	0.025 (0.008)***	39.233 (35.770)	X	↑
G7	-6.664 (9.741)	0.324 (0.457)	8.547 (12.267)	-0.809 (0.018)	0.008 (0.018)	11.937 (48.025)	X	X
United States	12.800 (3.651)***	-0.597 (0.171)***	32.483 (8.757)***	-2.721 (0.764)***	0.003 (0.008)	-164.731 (37.985)***	√	X
United Kingdom	-14.082 (4.374)***	0.671 (0.210)***	18.077 (3.462)***	-1.717 (0.350)***	-0.065 (0.013)	26.425 (25.171)	X	↓
France	-3.060 (20.260)	0.135 (0.963)	21.801 13.323	-1.996 (1.297)	0.078 (0.024)***	-42.548 (121.592)	X	↑
Germany	-40.725 (7.317)***	1.916 (0.346)***	36.453 (13.760)***	-3.443 (1.336)***	-0.021 (0.011)*	120.065 (30.869)***	X	↓
Italy	-39.339 (25.50)	1.871 (1.225)	4.604 (7.363)	-0.325 (0.773)	0.036 (0.016)**	191.792 (132.185)	X	↑
Japan	17.210 (38.444)	-0.771 (1.806)	6.283 (26.551)	-0.579 (2.609)	-0.020 (0.025)	-112.871 (196.973)	X	X
Canada	20.549 (12.955)*	-0.958 (0.809)*	-59.872 (78.919)	5.115 (6.598)	0.039 (0.018)**	65.426 (272.718)	√	↑
Panel	-4.721 (7.244)	0.220 (0.349)	4.290 (8.449)	-0.308 (0.757)	0.004 (0.011)	11.814 (37.393)	X	X

Standard error below coefficients in parentheses
***p<0.01 **p<0.05 *p<0.1

significance level, once the first difference has been taken for both real and per capita figures.

However, Pedroni (2004) noted that the three tests have a low power in the case of small-time dimension, suggesting that the tests do not account for heterogeneity, and therefore it is important to consider these findings as panel cointegration findings, the same was observed by Jobert *et al.* (2014). Subsequently, the results demonstrate

Table 7 - tests for cointegration results

Test statistics	Real Figures (1)		Per Capita Figures (2)	
	Level	1st difference	Level	1st difference
Kao test				
Modified Dickey-Fuller t	-0.5449	-7.2629***	-0.7852	-15.7347***
Dickey-Fuller t	-0.3014	-9.1517***	-0.4432	-12.5770***
Augmented Dickey-Fuller t	-0.5483	-5.5775***	-0.6542	-8.4354***
Unadjusted Modified Dicky-Fuller t	-0.4197	-23.2876***	-0.2448	-23.2926***
Unadjusted Dickey-Fuller t	-0.2205	-13.4910***	-0.1036	-13.5243***
Pedroni test				
Modified Phillips-Perron t	1.9881	-3.0053***	1.6902	-2.6670***
Phillips-Perron t	0.1022	-10.7393***	-0.7682	-10.1152***
Augmented Phillips-Perron t	-0.3212	-10.3122***	-0.7491	-9.7994***

***p<0.01 **p<0.05 *p<0.1

a long run relationship between CO_2 and all explanatory variables for the panel. Consequently, the panel cointegration equation can be written as:

(1) $lnC = -3.089 + 0.620 lnY - 0.014 lnYsq + 1.233 lnE$

(2) $lnCpc = -4.587 - 0.202 lnY + 0.0 - 3 lnYsq + 1.292 lnE$

Taking out energy consumption squared, as the results are statistically insignificant for both per capita and real figures.

5.4. Granger Causality

The casual relationship between the variables under consideration is evaluated by employing a Granger causality tests, the results are highlighted in table 8.

Table 8: Granger Causality Results

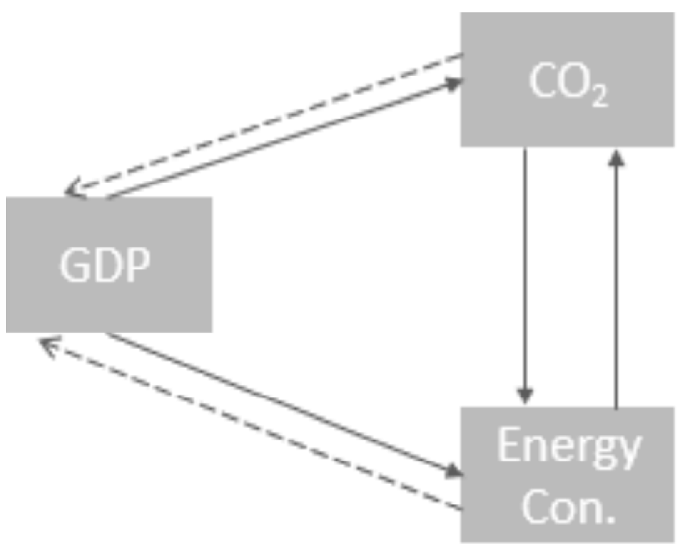
Equation	*Real Figures*		*Per Capita*	
	Chi2	*Prob.*	*Chi2*	*Prob.*
lnC ≠ lnY | lnCpc ≠ lnYpc	1.418	0.234	4.531**	0.033
lnY ≠ lnC | lnYpc ≠ lnCpc	7.378***	0.007	7.846***	0.005
lnC ≠ lnE | lnCpc ≠ lnEpc	2.885*	0.089	3.995**	0.046
lnE ≠ lnC | lnEpc ≠ lnCpc	5.156**	0.023	4.753**	0.029
lnY ≠ lnE | lnYpc ≠ lnEpc	4.499**	0.034	7.325***	0.007
lnE ≠ lnY | lnEpc ≠ lnYpc	1.966	0.161	4.969**	0.026

Ho: Excluded variable does not Granger-cause Equation variable
Ha: Excluded variable Granger-causes Equation variable
***p<0.01 **p<0.05 *p<0.1

For real figures, this study finds a unilateral causality between the natural log of GDP and CO_2 emissions, however, finds a bidirectional causality between these two variables in their per capita form. Likewise, the results suggest a bidirectional relationship between the natural log of CO_2 and energy consumption for both per capita and real figures. Finally, the unilateral causality between the natural log of GDP and energy consumption for real figures, and a bidirectional causality amongst these two variables in their per capita form.

Demonstrated in figure 12, this would suggest that an increase in GDP causes both an increase in CO_2 emissions and energy consumption, the latter two causing one another, shown in the solid lines. However, in per capita terms we see a causal relationship between CO_2 and energy consumption to growth in GDP, demonstrated through the dotted lines. These results are similar to the findings of other studies (Ang, 2007) (Pao and Tsai, 2010) (Danish *et al.*, 2019).

Figure 12: Panel Casuality relations for BRIC & G7 Countries



5.5. Paris Agreement

To analyse the effects of the Paris Agreement, a dummy variable was added to the regression analysis, suggesting a structural break when the agreement came into force in 2016. The results for the panel from the random-effects regression analysis indicate a decrease of 2.7 percent year on year, in real terms, since the signing of the agreement, suggesting a positive outcome for the agreement. A similar result was found for per capita figures, showing a 2.6 percent decrease.

However, when analysing the results for each individual country within the panel, this study finds mixed findings. First focusing on BRICS countries, Brazil is the only country within this group to have shown a decrease in CO_2 emissions since the signing of the agreement, for both real (5.6 percent) and per capita (4.5 percentage). China and South Africa both find a statistically significant increase in per capita CO_2 emissions since the signing, with China also showing a statistically significant increase in real levels of CO_2. On the other hand, Russia and India's findings are statistically insignificant.

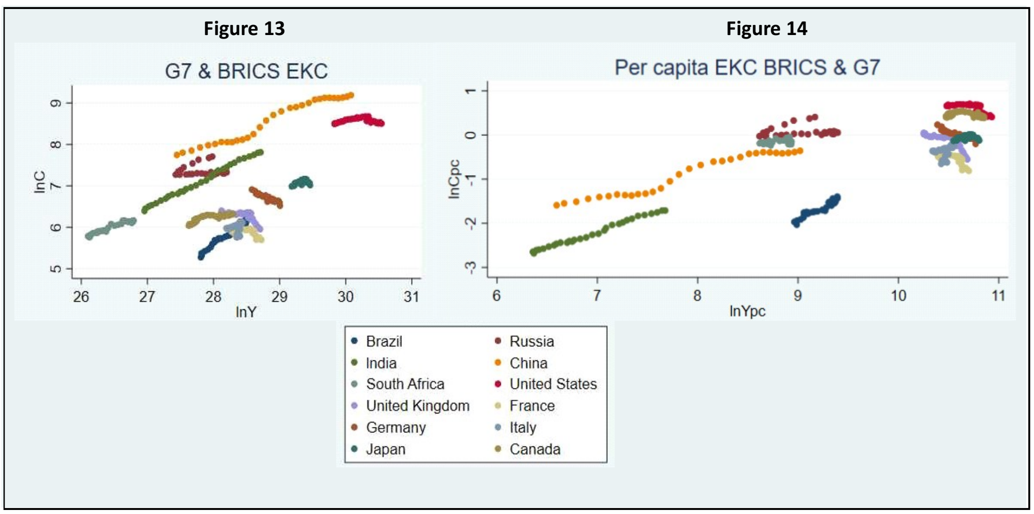
Analysing the G7 countries findings, table 5 reveals a decrease in all G7 countries for real level CO_2 emissions at a 1 percent significance level. For the combined panel of G7 countries, a decrease of 12.9 percent is reported. With the largest year on year decrease in the United Kingdom, estimating a 21.2 percentage decline since the signing of the agreement, and the smallest decrease being shown in Canada, at 9 percent. When analysing the per capita figures for the G7 countries, the results are more mixed. We continue to see a significant decline only in Germany, and an increase in per capita CO_2 emissions in France, Italy, and Canada. These findings differ some those found in Callaghan and Kumazawa (2010), who found the signing of the Kyoto Protocol to be effective for developed economies, and unchanged in emerging economies. However, it is important to note that Callaghan and Kumazawa (2010) do not analyse countries separately, instead run a panel for each group of economies.

5.6. Hypothesis Analysis

This section will make the concluding remarks on each of the null hypotheses highlighted in section 2 of this paper.

Hypothesis one, the relationship between GDP and CO_2 emissions follows an EKC, can be accepted for only a limited amount of the countries within the panel. The findings establish two focal patterns the CO_2-GDP nexus follow. The first is the traditional inverted U-shape relationship, known as an EKC. This can be found for Brazil, China, South Africa, the United States, and Canada for real figures, and the same for per capita figures, apart from South Africa which did not show as statistically significant. This means that for these countries, the null hypothesis can be accepted. The second common pattern is a U-shape relationship, suggesting that as economic growth increases, emissions will decrease, until a certain point, and then begin to rise again. This pattern can be found for the United Kingdom and France in real and per capita terms, and for Russia in just per capita terms. This concave relationship has also been found in other studies which account for heterogeneity within their panels (Mazzanti and Musolesi, 2013) (Jobert *et al.*, 2014). Alongside this, the granger causality findings suggest that CO_2 emissions react to changes in GDP. Figure 12 shows the individual CO_2-GDP relationships for real and per capita figures respectively.

Figure 13 & 14: CO_2-GDP relationships in aggregate and per capita terms for G7 and BRICS Countries



These findings are in line with Jobert *et al.* (2014) findings, demonstrating the existence of an EKC for all countries combined in the panel, nevertheless, finding different relationships when accounting for heterogeneity. This study identifies differences in developed and undeveloped countries, even if together they held 68 percent of both world GDP and CO_2 emissions in 2019.

The second and third hypotheseses are examined using the results from the Granger causality. The second null hypothesis states that there is a positive causality between energy consumption and GDP, while the third hypothesis states there is a causality between energy consumption and CO_2. These two hypotheses cannot be assessed on an individual country level as the Granger causality assesses the whole panel. We can accept both of these hypotheses, as the study finds a statistically significant causality from GDP to energy consumption, and a bidirectional relationship between energy consumption and CO_2 emissions.

The fourth null hypothesis stated that the signing of the Paris agreement has caused a decrease in CO_2 emissions. This can be accepted when referring to the overall panel of countries, showing a rate of -2.7 percent decline in real terms. However, this hypothesis is rejected for all BRICS countries besides Brazil for both real and per capita figures. All G7 economies can accept the hypothesis for a decline in real level CO_2 emissions since the signing, however only the United Kingdom and Germany show a decline for per capita figures.

A significant finding of this study is the variance between real and per capita figures for G7 countries. With all countries showing a statistically significant decline in real terms, it is surprising to find only the United Kingdom and Germany declining in per capita figures. These results suggest that for many countries, CO_2 emissions are growing faster than the population, a particularly important finding for the UN to be aware of when measuring the successfulness of the Paris agreement, opening potential doors for future amendments to overcome this.

With previous empirical research on the Paris agreement by Liu et al (2020) suggesting the largest reduction in emissions will need to be from China, followed by the US for the agreement to be successful, it would be a promising sign to see a reduction in their findings since the signing. While a reduction can be seen in the US real levels of CO_2, the results for China indicate an increase in emissions since the signing, for both real and per capita levels. Likewise, a lack of reduction in the BRICS CO_2 emissions (besides Brazil) has been observed, signifying that the support being given to developing/emerging economies is not significant in curving their emission patterns.

The final null hypothesis, BRICS and G7 economies have different income-energy-output nexuses, can overall be accepted. The results imply that not all countries show the same trends and therefore, this in an important finding for the UN and individual countries to consider when tackling climate change. No two countries will show identical patterns, and therefore heterogeneity needs to be accounted for when making policy decisions. This can be reflected in the UN Paris Agreement, noting that each country has individual reduction targets.

Alongside this, by employing equation 3 (p.22), this study estimates the optimal level of GDP to ensure CO_2 emissions are at their lowest level for each individual country. Table 9 summarised the findings, with columns 'Yit = lowest CO2' showing the optimal level of GDP, and per capita GDP, respectively.

Table 9: Optimal GDP growth

Country	(1) Real Figures				(2) Per Capita Figures			
	ß1	ß2	Y_{it}	Y_{it} = lowest CO2	ß1	ß2	Ypc_{it}	Ypc_{it} = lowest CO2
Brazil	51.722	-0.928	27.867	1,266,726,204,641**	25.543	-1.425	8.962	7,804.5023*
Russia	-2.963	0.053	27.953	1,379,621,343,502	-2.031	0.109	9.317	11,120.147***
India	-0.016	-0.001	-8.000	0	-0.422	0.024	8.792	6,579.188
China	4.932	-0.088	28.023	1,479,502,905,653***	1.282	-0.094	6.819	915.206***
South Africa	10.872	-0.203	26.778	426,264,176,291**	-3.988	0.242	8.240	3,788.288
United States	13.713	-0.229	29.941	10,074,695,852,161*	12.8	-0.597	10.720	45,264.032***
United Kingdom	-30.858	0.543	28.414	2,188,778,279,571***	-14.082	0.671	10.493	36,072.771***
France	-10.706	0.183	29.251	5,054,833,955,165	-3.06	0.135	11.333	83,561.096
Germany	-37.129	0.64	29.007	3,959,073,899,176**	-40.725	1.916	10.628	41,258.383***
Italy	-14.048	0.240	29.267	5,132,770,391,468	-39.339	1.871	10.513	36,784.335
Japan	9.703	-0.154	31.503	48,049,207,272,926	17.210	-0.771	11.161	70,321.305
Canada	27.350	-0.492	27.795	1,177,854,226,804*	20.549	-0.958	10.725	45,476.355

***p<0.01 **p<0.05 *p<0.1

Note: significance levels are taken from ß1and ß2coefficients

When analysing the statistically significant results, it can be observed that optimal GDP per capita is lower in BRICS countries than in G7 countries, similar findings are found for the real GDP levels. This would reinforce the acceptance of hypothesis 5, suggesting emerging economies experience worsening CO_2 levels while developing, therefore the table suggesting that a previously low level of GDP is preferable for a low level of emissions. However once more developed, like that of the G7, minimum levels of CO_2 can withstand higher levels of GDP. This can be down to the advances in technology and renewable energy resources being more accessible in the established economies.

6. Ethics, Limitations and Reflections on the process

6.1. Ethics

This studies data is entirely obtained through secondary data sources; therefore, limiting any potential ethical implications that can rise from research. However, it is important to note that limitations can arise from where data is obtained from, and thus this study has only used data from credible sources such as World Bank and BP Global Statistics. Alongside this, to avoid plagiarism all literature will be properly credited by correct referencing.

6.2. Limitations

When analysing the Paris agreement, it is recognised that additional years of data after the signing will give a more comprehensive long-term conclusion of the effectiveness of the agreement. As previously mentioned, cointegration tests are not always the most accurate source of long-run relationships for panel data, and therefore the results should be interpreted with caution.

Although highly studied, the EKC often gets criticised for its lack of attention to individual country differences, and future prospects of growth. Although this study has tried to overcome the limitations around homogeneous estimators, this study does not account for different routes of development. A lot of empirical research recognise India's growth strategy to be different to that of others, limiting their industrial development and instead expanding their economy through the service sector. The services sector is significantly less polluting to that of industrial sectors, and therefore not picked up on in the EKC hypothesis.

6.3. Extension/Future research

Based off these highlighted limitations, future research would be beneficial in understanding the long-term effects of the Paris agreement, once additional years of data becomes available. Alongside this, further research could be conducted to expand the explanatory variables. Due to limited scope and time, this study was unable to focus on multiple explanatory variables, however it is recognised that it would be beneficial to help understand different economies growth strategies, such as India, mentioned above.

6.4. Reflections on the process

Overall, I found the process to be challenging. As somebody who has never studied econometrics before, I found it daunting to learn and apply these techniques with confidence, whilst also learning a new analysis tool (Stata). To overcome these hurdles, I had to dedicating a lot of time to learning and understand new estimation methods and being open-minded to adapting my research as I gained more knowledge on the topic. During the past few months of completing this thesis, I have developed my project and time management skills, whilst having to juggle dissertation work with other university modules and personal life. As well as gaining skills in econometric analysis and academic writing, both of which I hope to use and develop in the future, making me open minded to completing a research Masters.

Overall, I've found the topic area to be extremely interesting, and I've enjoyed being able to combine my degree knowledge around the importance of economic development with my passionate for sustainability and environmental climate change.

7. Dissertation Conclusions and Contributions

This research set out to investigate whether economic growth has an impact on CO_2 emissions in G7 and BRICS countries, and whether the Paris Agreement has been effective in respect to CO_2 emissions by successfully analysing each of the five null hypotheses. This was achieved through analysing the 12 countries between 1990 to 2019. A panel AMG method was applied as the main econometric estimator, being able to account for both CD and heterogeneity, it seemed to be the most efficient panel estimation method. The findings differing when analysing the all countries in the panel together, to when examining individual relationships. Alongside this, cointegration and causality tests were applied to help understand the relationship between CO_2, GDP, and energy consumption. The robustness of the panel data analysis is checked by employing both per capita and real figures for all 12 countries.

A key finding from this study is that the EKC hypothesis does not stand true for all individual countries. Although, a long-run equilibrium relationship between CO_2 emission, GDP, and energy consumption for the entire panel is found for real level figures, individually the results vary. Saying this, the findings suggest a long-run equilibrium relationship between CO_2 emissions, GDP, and energy consumption and strong causality between variables.

Alongside this, the decline in G7 countries real level CO_2 since the signing of the Paris Agreement and the results of the optimal GDP level both support the differences between BRICS and G7 countries. These findings support the Green Solow Model (Brock and Taylor, 2010), suggesting that once a countries growth rate stabilises, technological progress can lead to a decline in CO_2 emissions, tending towards net zero emissions. Acknowledging that continued economic growth brings greater harm to the environment is critical for the design of appropriate developing strategies for emerging economies and understanding whether the ambitious aims of achieving net zero emission by 2050 can be achieved at the current pace of change, this reinforces the Paris agreement's suggestion of developed countries taking the lead on reducing emissions seem to be a far and realistic predication based on this studies results.

These findings are extremely topical for the 26^{th} UNFCCC conference in Glasgow this upcoming November, with an agenda for every country to outline their emission reduction targets, it is important for countries to be aware of their current climate patterns, especially when it concerns the 12 countries which hold 67.7 percent of world GDP (2019 figure).

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