Regional differences in sustainable development:

An Environmental Kuznets Curve analysis

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Abstract

The Environmental Kuznets Curve (EKC) is commonly associated with the question if economic growth could be the solution to the environmental crisis, with early empirical focus on developed countries. The EKC discussion has since evolved into a generic framework of analysing relationships between environmental and economic indicators, and has proved to become a useful tool of modelling this relationship. This study aimed to give a theoretical and empirical overview of the Environmental Kuznets Curve hypothesis, and examined the relationship between carbon dioxide emissions and Gross Domestic Product in the context of developing countries and in relation to the mechanisms of the curve. This was done by modelling the curve on four sets of panel data containing countries from four regions of developing countries (Latin America, Asia, West and East Africa) using the panel fixed effects model and the quadratic specification of the EKC. In addition the study conducted a Granger-causality analysis across the combined panel in order to examine the underlying dynamics of the variables.

The result of the panel fixed effects model showed that there are differences in sustainable development, with significant evidence of an inverted U-shaped EKC relationship in Latin America, qualitatively but less statistically significant evidence of the same in Asia, but the reverse relationship in both of the African regions. The causality analysis found evidence of a bi-directional relationship where carbon dioxide and GDP might Granger-cause each other. The findings suggest the need of less carbon intensive energy production and stricter environmental regulation in developing countries.

Acknowledgements

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Contents

Glossary

CO_2 carbon dioxide. 7, 13, 17, 19

NO_x abbreviation for both nitric oxide and nitrogen dioxide. 13, 15

SO_2 sulfur dioxide. 13, 15

carbon intensity The ratio between carbon dioxide emissions per kilowatt hour of electricity. 18, 33

cointegration Long term trend between two time series processes. 8, 23, 24

EKC Environmental Kuznets Curve. 6, 7, 15

energy intensity The ratio between energy consumption and GDP. 17, 18, 31, 33

GDP Gross Domestic Product. 16, 19

GNI Gross National Income. 16, 19

Granger-causality A statistical method of describing potential causality, as suggested by Granger (1969). 8, 14, 17, 23, 24, 29, 32

PPP-adjusted GDP per capita Purchasing Power Parity adjusted Gross Domestic Product per person, this indicator is adjusted for currency strength and inflation. 7, 19

SPM suspended particle matter. 13, 15

Chapter 1

Introduction

The ending of the ongoing environmental crisis seems to be no where in sight, in contrast, despite international agreements such as the Paris-agreement in 2015 and more recently COP 27 hosted by Egypt, there still is a sense of passivity from the international community as a whole. Acemoglu et. al (2012) named this passivity *laissez-faire* or business as usual, and warned of a disaster if the environmental degradation is not kept within a critical limit. William Nordhaus emphasized the potential economic and societal cost of this business as usual approach when constructing his Nobel price winning integraded assesment model[1] DICE (Nordhaus 2018). A possible explanation of the passivity is the observation that countries seem to become more sustainable as they develop economically, in a relationship called the Environmental Kuznets Curve (EKC), which proposes an inverted U-shape in the relationship between environmental degradation and economic growth (Grossman & Krueger 1991; Panayotou 1993).

The basic intuition behind the hypothesis is rather simple and is made up of three effects, as countries become richer they expend more energy and thus pollute more which is called the *scale effect*, and forms the upward sloping part of the curve. At a certain point of economic development, the demand for a cleaner environment manifests in environmental regulation and moves the polluting production to somewhere with comparably less regulation, which is called the *composition effect* and makes up the so called turning point. Finally scientific advances enable cleaner production methods and due to the *technological effect* the slope of the EKC points downwards. This naturally raises the question of what progress that has been made around the world. Particularly interesting is the

[1] An integraded assesment model (IAM) is a tailor made model for modelling different scenarios of the cost of different climate mitigation strategies, usually highly detailed but with a restricted scope of subject and time (Pauliuk et. al 2017).

case developing countries as it raises even more questions. For instance, some credit the composition effect to a phenomenon called the pollution haven hypothesis (Levinson & Taylor 2004; Tanaka et. al 2021) which suggest that due to differences in environmental regulation, production that includes greater environmental impact will be moved from developed to developing countries. Others suggest that the technological effect will lead to the advent of an eco-economic decoupling where a transition into a service economy would decouple economic growth from environmental degradation (UNEP 2011), this notion has been criticized however and Kander & Henriques (2010) argued that the transition to a service economy only would result in a modest environmental relief.

The Environmental Kuznets Curve provides a generic framework for analysing a wide variety of pollutants in relation to some economic growth measure and control variable(s), which can be applied to different countries or regions over time. This enables researchers to be more flexible in their analyses, which is more appropriate for this study. This thesis is intended to be a descriptive study, using the EKC hypothesis to try to answer the questions: Is there a difference in sustainable development in the four regions? Can the regions be described by the inverted U-shaped Environmental Kuznets Curve? And is there a causal relationship between carbon dioxide and GDP? As such, this study intends to take an *insight not foresight* approach as suggested by Pearson (1994), and the empirical part is intended to describe the potential shapes of the curve whilst not trying to predict when the turning point would occur.

The empirical approach of this study uses the quadratic specification of the Environmental Kuznets Curve, as it is interested in the inverted U-shaped variant, or the initial bend of the curve. In order to estimate the EKC shape of the different regions, this study will use a panel fixed effects estimator following the result of a Hausman test. In addition, it intends to primarily discuss the implication of the potential causal relation between environmental degradation and economic growth. As such, this study intends to examine panel data on four regions of developing countries in west and east Africa, Latin America and Asia over the period 1960-2016. The reasoning behind the choice of regions is to give a base for comparative analysis between different regions of developing countries around the world, given that countries generally develop similarly to their neighbours (Moreno & Trehan 1997), the variation within the groups should be less than the variation between the groups and therefore interesting to compare. The data on the main explanatory variable, PPP-adjusted GDP per capita, is provided by the Maddison project version 2018 (Bolt et. al 2018), the data set is categorized by continent and sub-region, which are used in the groupings of this study. The dependent variable, carbon dioxide (CO_2), is sourced from free material provided by Gapminder (n.d) which is calculated as tonnes of CO_2 emissions per capita. On the data-wide level unit root test was employed in order to check for stationarity, cointegration test was used to establish long term correlation between the variables and a Granger-causality test was performed in order to examine the causality directions of the variables.

The results found mixed evidence of the Environmental Kuznets Curve in the regions, with significant evidence for the presence of the potential inverted U-curve was Latin America, furthermore there was evidence of a turning point in the Asia data set, however with less statistical significance. The West Africa data set found significant evidence of an U-shaped EKC when only considering individual effects, while the East Africa sample only found evidence of further emissions when GDP squared increases. Diagnostic tests found that the variables were cointegrated and the Granger-causality test suggested a bi-directional causality link between the variables. The theoretical conclusion were that there are large differences in emissions as the different regions developed, that two (Latin America and Asia) of the four regions could be described with the inverted U-shaped EKC and that there might be a bi-directional causal relationship between CO_{pc}^2 and PPP-adjusted real GDP_{pc}.

This study could contribute to the literature by attempting to use the Environmental Kuznets Curve as a platform for comparative analysis using clusters of countries on a global scale as opposed to individual countries or a single panel as opposed to (for instance) Ahmad et.al (2021) or Apergis (2016). This approach emphasizes the global nature of this issue, as it is not likely that the actions single countries will be the key to solve it. The findings of this study suggests that investments in renewable energies and stricter environmental regulation is needed in developing regions in order to counteract the adverse effect of economic growth.

Chapter 2

Literature

2.1 Theoretical background

This section will give an overview of the theoretical and econometric background of the EKC literature, with section 2.1.1 discussing the the theoretical mechanisms, about why and how the curve is formed, while section 2.1.2 gives an overview of the econometric methods usually employed when doing empirical research related to the EKC hypotheses, as well as a discussion of what method is used in this study.

2.1.1 Mechanisms of the Environmental Kuznets Curve

The Environmental Kuznets Curve has become one of the more popular frameworks in which to describe the environmental impacts of economic growth. An important part however is to understand the economic mechanisms that drives it. According to Grossman & Krueger (1991), the mechanisms are made up of three distinct effects; these are scale effects, composition effects and technique effects. The last two are also often called structural respectively technological effects (Biligi et. al 2016), which can be seen in figure 2.1.

The scale effect implies, as described by Grossman & Krueger (1991) that as the economy expands, it will require more energy which in turn results in environmental degradation. This theoretically causal relationship follows the straightforward intuition of supply and demand at the cost of the environment, and has been frequently tested and reinforced by empirical evidence, this evidence also suggest a bi-directional causality between emissions and GDP (see section 2.2.2).

Composition effects suggests that a globalized world will lead to countries specializing in production of certain types of goods and services, this could be because of traditional comparative advantages or as a result of less stringent environmental regulation in less developed countries (Grossman & Krueger 1991). In essence the more developed countries exports polluting industries to less developed ones. The general characteristics of composition effects can be illustrated in the pollution haven hypothesis, as proposed by Levinson & Taylor (2004). While the discussion of the potential adverse environmental effects in foreign countries caused by the environmental regulation in the home country, have been active previously (Jaffe et. al 1995). Levinson & Taylor (2004) pioneered the concept of the pollution haven hypothesis by showing how abatement efforts lead to an increase in net imports. A recent empirical example is given by Tanaka et. al (2021), where stricter regulation of air-quality in the USA lead to an increase in production in battery-recycling plants in Mexico.

Technique effects refer to changes in output of pollution per unit produced as new technological innovations gets implemented in the production process. This change could be a result of the diffusion of cleaner technologies, machines or production methods from more developed countries to less developed, it could also be a consequence of political pressure from the local populace to improve environmental regulation as national wealth increases (Grossman & Krueger 1991). Some have speculated, (Zoundi 2017) that the technological effects would lead to the advent of the so called service economy, where environmental degradation is decoupled from economic growth. The United Nations Environment Programmes (UNEP) 2011 decoupling report gives an overview of the subject and notes that decoupling has become a primary objective for various agencies and bodies, such as the OECD and the European Union. Decoupling can however be manifested and described in different ways, first of all, there is a difference between resource decoupling which refers to a decline of materials used in the economy and impact decoupling which refers to environmental improvement as economic output increases. Another point of variation in the decoupling concept is absolute versus relative decoupling. Relative decoupling is when the negative change in environmental degradation is less than the positive change in economic prosperity, which means that while the relation is positive, the elasticity is less than one. Absolute decoupling on the other hand requires environmental impacts to decrease regardless of the change in economic growth or activity (UNEP 2011:2-5). The concept of decoupling has faced criticism however and Henriques & Kander (2010) argue that the environmental gains from the transition to a service economy would be slim, this according to the authors, is due to a price illusion: even though the service sector claims a larger share of the GDP, the real production of the manufacturing sector remains constant. This price illusion could thus be accounted for by using constant or real GDP when calculating sector shares.

The Environmental Kuznets Curve can exhibit different shapes depending on model specification, with the two most common being the inverted U-shape and the N-shape. The N-shaped variant, which is expressed by a cubic specification is described by Torras & Boyce (1998), where the authors found evidence of decreasing air and water quality in high-income countries. The mechanisms of the N-shaped curve is discussed by, among others, Álvarez-Herránz & Balsalobre (2016) which defines a fourth effect, *technological obsolescence*. This effect occurs in high-income level countries as a result of insufficient regulation and management of energy, which leads again to increasing pollution levels. Figure 2.1 displays the path of the N-shaped EKC reproduced from Sinha et. al (2019). As this effects chiefly concerns developed, high-income countries, it is of little relevance for this study. In the same vein as Panayotou (1993), Munasinghe (1999) questioned if increased pollution was inescapable in order to obtain a high level of economic development, and argued that with preemptive measures and environmentally friendly policies, countries could avoid the adverse effects of growth inducing reforms which makes it possible for countries to *tunnel through* the EKC curve, this could also imply that technique effects has to occur after the compositions effect. Dasgupta. et al (2002) also proposed different scenarios for the path of the Environmental Kuznets Curve, reproduced in figure 1.2, below. In addition to the conventional EKC, the authors propose three different scenarios, first an optimistic model resembling Munasinghe (1999), the second model *Race to the Bottom* describes a scenario where increased pollution is restricted by inducing autarky, restricting both trade and foreign investment in order to combat pollution havens. The third and most pessimistic scenario appropriately named *New Toxics* predicts that an industrial society will continually generate new and unregulated pollutants even if others are reduced.

2.1.2 Econometrics of the Environmental Kuznets Curve

There is no general scientific consensus on the shape and validity of the EKC relationship according to Bhattacharya (2019). This is due to the varied nature of the methods used, countries observed and variables considered. Generally however, EKC studies suffer from the same type of problems, which are described by Sinha et. al (2019). In addition to a comprehensive overview of the different variations of EKC studies, Sinha and colleagues outline three problematic areas when constructing an EKC study; model selection and

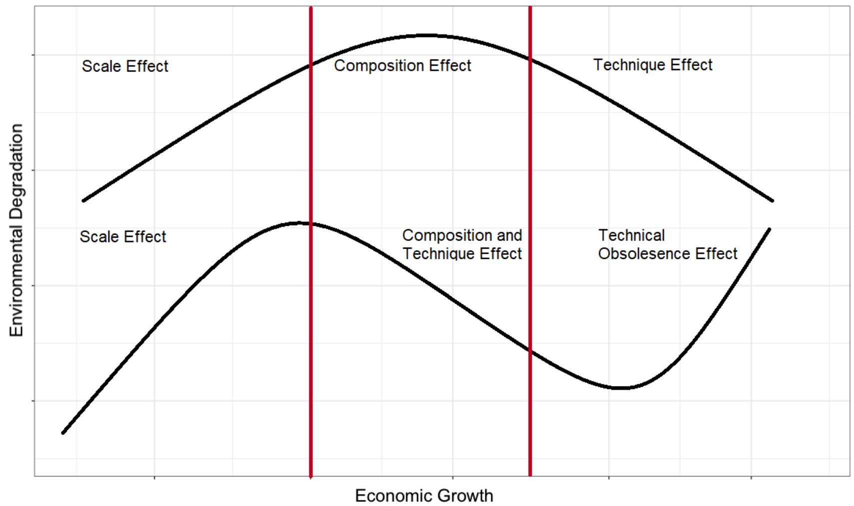

Figure 2.1: The quadratic (inverted U-shape) and cubic (N-shaped) specifications of the Environmental Kuznets Curve, reproduced from Sinha et. al (2019).

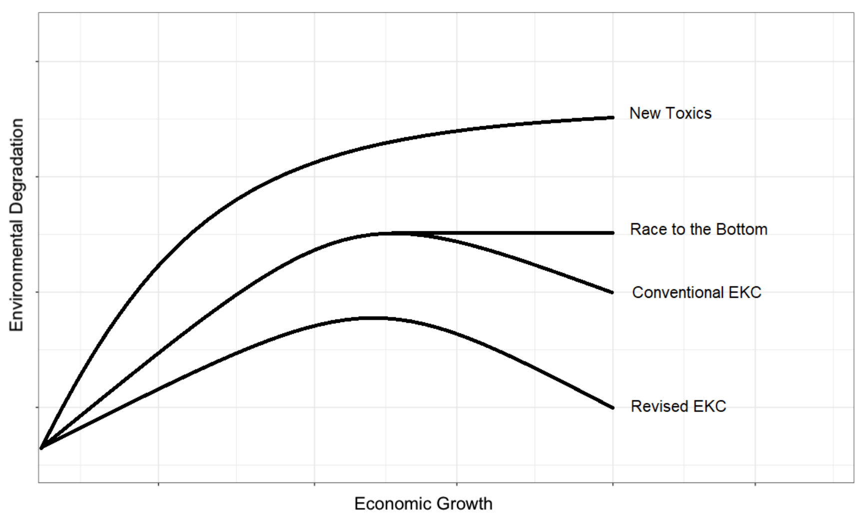

Figure 2.2: Different scenarios of the Environmental Kuzets Curve, reproduced from Dasgupta et. al (2002).

validation, data availability and variable selection, and finally choice of environmental proxy.

Regarding the choice of model, there are two main specifications: The inverted U-variant, also called the quadratic specification, or the N-shaped cubic specification. This study will use the quadratic specification as it is interested in developing countries at earlier stages of their growth path. A quadratic model is expressed in mathematical form as

$$ED = b_0 + b_1 P + b_2 P^2 + \varepsilon,$$

where ED is some indicator of environmental degradation and P is some indicator of prosperity. $b_1 > 0$ implies that environmental degradation increases as prosperity increases and $b_2 < 0$ implies the presence of a local maxima or turning point, hence the conditions for an inverted U-shape is valid if $b_1 > 0$ and $b_2 < 0$ with a turning point at $\mu = \frac{-\beta_1}{2\beta_2}$ (Sinha et. al. 2019).

Data availability has been a central issue of early EKC studies, where most were restricted to a cross-sectional setting which according to Sinha et. al. (2019), as discussed in section (2.2.1). Instead, improved data availability enabled the popularization of time series data and panel data for analysing single and multiple countries respectively. Regarding variable selection, designing a EKC study requires a balance between omitted variable bias and misspecification bias, as each region and time period presents unique scenario, therefore studies usually control for a large number of variables when testing the validity of the EKC relationship (for example see Cole et. al (1997)) or a smaller number when examining the effects of a particular variable (Shahbaz et. al 2013; Lau et. al 2014; Bilgili et. al 2016).

The issue of which environmental proxy to be used is also discussed in Sinha et. al (2019). While CO_2 is the most common proxy used in EKC studies, there has been studies that has considered other pollutants as well, for instance pollutants of a more local nature as NO_x, SO_2 and suspended particle matter (SPM). The issue with using local pollutants is that they can be internalized by the country by relatively inexpensive abatement (Dasgupta. et al 2002; Rothman 1998; Suri & Chapman 1998; Cole et. al 1997). The intuition behind this, is that as the adverse effects of local pollutants are clearly visible to the populace, it puts pressure on the government to reduce it. An interesting argument made by Pearson (1994) however is that abatement of local pollutants could be a major driver of the composition effect. Carbon dioxide CO_2 in meanwhile is considered a global pollutant, meaning that each individual country has less incentive to internalize the pollution (Dasgupta et. al 2002). Sinha et. al (2019) also raises the point that only local pollutants can be attributed to a particular country while CO_2, as a consequence of its global nature might, not be a result of production and consumption in the specific country. Hence the authors recommend CO_2 as measured by emissions to be considered in a cross-country setting and local pollutants to play a greater roll in the analysis of a specific country.

Another point of variation between EKC studies is the statistical methodology used. As different methods are used by time series and panel data studies, primarily panel data methodologies will be considered here. Lau et. al (2019) gives an overview of different estimators used currently and in the past, in addition the authors provides insight into various diagnostic tests useful in order to improve the inference based on the estimations. Over the years, different estimators has been utilized, ranging from simple ordinary least squares (OLS) to generalized least squares (GLS) and fixed/random effect (as used in this study), and more recently fully modified and dynamic OLS (FMOLS and DOLS) to generalized method of moments (GMM), each with accompanying pros, cons and criticisms. Another factor to consider is stationarity (as GDP for instance is usually assumed to be at least trend stationary) and as such, EKC studies usually incorporate some form of unit root test, with modern ones including tests for cross-sectional dependency, in order to account for correlation caused by uneven effects of common shocks and local spillover effects. Due to the nature of the variables considered in an EKC study, a cointegration test is also common, as GDP and CO_2 is generally considered to follow the same long term trend, cointegration also means that OLS will be consistent (Vogelsang & Wagner 2014).

On a related note, and as shown in section 2.2.2, causality studies featuring Granger-causality tests has become a common parallel subject of EKC research (Lau et. al 2019), as it is usually performed in addition to estimations of the parameters of the curve. This is related to the implications of the scale effects, given that economic activity creates emissions but also that increased energy use involved in economic activity (such as production and transportation), implies some form of emissions (which could be the source of the simultaneity issues as described by Stern et. al (1994) discussed in section 2.2.1). This causal relationship is often estimated by what is commonly referred to as Granger-causality, which is a method created by Granger (1969) in order to attempt to discern causality directions, is more accurately described as a gauge of one variables ability or usefulness to forecast another variable, and should not be interpreted as true causal effect (Dumitrescu & Hurlin 2012).

2.2 Empirical studies

The following section contains two parts: The early and seminal works which will be discussed in 1.2.1 and more recent and relevant studies in 1.2.2. For a comprehensive overview of the EKC literature, from which this section has relied upon, The author would recommend Bhattacharyas and Inglesi-Lotzs respective chapters in Özcan & Öztürk (ed.) (2019).

2.2.1 Early studies and initial critique

In a working paper, Grossman & Krueger (1991) examined the potential environmental effects of economic integration as a consequence of NAFTA, the free trade agreement between Mexico, Canada and the United States. They based their analysis on a polynomial expression linking air pollutants to economic growth and discussed their results in relation to three effects: scale, composition and technique effects (these effects, and potential shape of the curve, will be expanded upon in section 1.3.1). Their findings where that for two pollutants, SO_2 and dark matter (smoke), the concentration increased at low levels of development but decreased at higher levels creating the inverse U-shape. In addition, the authors found evidence of, at even higher levels of national income, the concentration of these pollutants could increase again, resulting instead in a N-shaped curve. This result was generalized by Panayotou (1993) in relation to a hypothesis borrowed from Simon Kuznets (1955), which assumes an inverted U-shape between income inequality and economic growth. The Environmental Kuznets Curve or its abbreviation EKC, thus assumes an inverted U-shape between rate of environmental degradation and level of economic development. Furthermore Panayotou (1993) established the hypothetical turning point of the relationship, that being, the dollar value of where environmental degradation begin to decrease, and found turning points for deforestation, SO_2, NO_x and suspended particle matter (SPM) while examining both developed and developing countries. Finally they discussed potential implications and policy suggestions and emphasized that while the EKC might be an mechanical result of economic growth, developing countries could flatten their curve by implementing appropriate policy measures. Note however that the author does not specifies what flattening the curve means, as emissions is calculated by yearly emissions, an argument could be made that a steeper curve that reaches its turning point earlier would be preferable in order to minimize cumulative emissions.

The EKC hypothesis has since gained popularity, and in the following decades became a useful framework for examining various environmental indicators in relation to economic development, regressing some proxy for environmental degradation on a single explanatory variable, typically GDP or GNI. However early on, critical voices elucidated theoretical as well as statistical issues. As an example of the theoretical discussion, Suri & Chapman (1998) argue that the upward and downward slopes of the curve is a result of trade directions, where industrialized countries could decrease their rate of environmental degradation by importing foreign goods and vice versa. On a similar note, Rothman (1998) put forward a case for using a consumption based approach in order to more accurately account for the capability of actors in developed countries to disassociate themselves from their consumption's environmental impacts. Other authors question the importance of turning points, particularly in the case of developing countries, as the predicted turning points might mislead policymakers (Richmond & Kaufman 2006).

Statistical and econometric issues has also been frequently discussed, Stern et. al (1994) together with Pearson (1994) focused their critique on potential simultaneity problems in cross-sectional evidence. This simultaneity stems from the nature of the variables and the scale effect previously mentioned, as the latter implies, when emissions increase so do economic activity but at the same time, when economic activity increases so do emissions. This have made it hard for researchers to differentiate causality direction, in other words, does economic activity lead to emissions or the other way around? Pearson (1994) further argued the theoretical problem that, if the EKC relationship is true and holds, it could harmfully simplify the complex dynamics processes underneath, which could lead to subpar policy decisions. Cole et. al (1997), also critical of the early and simple econometric models, instead looked at multiple indicators using cross-country panel data and found that only local pollutants exhibits the EKC shape, while global pollutants do not. Finally Stern (2004) drew the conclusion that the statistical methods used in the earlier literature was essentially inadequate, and that without concern given to issues such as omitted variables bias and cointegration, the inference of some studies could be questioned. Instead Pearson (1994), Stern et. al (1994) and Stern (2004) recommend using panel data coupled to gain observations and reduce simultaneity bias by differentiating between trends, coupled with some form of decomposition model in order to decompose the influences on the demand and supply side, in other words, attempt to more accurately track causal direction.

A lot can be learned from these early works, but a few key takeaways is that there is evidence of a relationship between environmental degradation and economic development that can be described as an inverted U-shape. On the other hand theoretical and statistical critiques question the inference and policy potential of the early results, with special emphasis on the usefulness or lack thereof of turning points. The discussion on the Environmental Kuznets Curve has continued to evolve however, and in response to the critique of the early studies, new methods has been developed including advanced econometric models incorporating more variables.

2.2.2 Recent and related studies

The modern EKC literature can be roughly divided as single country and multiple country studies but are generally concerned with examining carbon dioxide emissions, CO_2, in relation to some other variable or variables. In addition, improved statistical methods has enabled researchers to more accurately model causality directions and greater data availability over longer time horizons for different variables have made it possible to conduct panel data research. As of most relevance to this study, literature regarding multiple countries using panel data, and more specifically, developing countries will be highlighted along some single country studies including causality estimations and variables of particular interest.

Effects focused and Granger-causality studies has become increasingly popular, Shahbaz et. al (2013) investigated the effects of globalization in a single country study of Turkey over the years 1970-2010. The study used causality tests in order to examine the relation between CO_2 and energy intensity, which is the ratio between energy consumption and GDP and found that the effects of globalization lead to economic growth which increased emissions while still validating the presence of the EKC. Their causality analysis found a bidirectional causality between emissions and economic growth. Furthermore Lau et. al (2014) looked at trade and foreign direct investment (FDI) in Malaysia over the period 1970-2008 estimating the EKC coefficients and Granger causality and found similar results, evidence of the Environmental Kuznets Curve and both direct and indirect link between FDI, trade and CO_2 emissions. In a multiple country study, Biligi et. al (2016) considered renewable energy consumption in a panel data setting containing 17 OECD countries. The authors used long-run panel estimators and found evidence of an EKC relationship, that renewable energy consumption effects CO_2 emissions negatively and that EKC does not depend on level of economic development. Similarly, using estimators of long and short-run causality, Ahmad et.al (2021) found that an increase electric power consumption and real GDP per capita in developing countries could have a mitigating effect on CO_2 emissions. Furthermore the authors found evidence of a bi-directional causality for of GDP per capita, CO_2 emissions and electric power consumption.

There have also been recent studies on the regions which this study is interested in, for instance Boutabba et. al (2018) looked at 17 Sub-Saharan countries 1995-2013 and how trade in intermediate goods influences carbon emissions. Using panel cointegration and causality estimations, the authors found that trade in intermediate goods can mitigate CO_2 emissions, as well as evidence of the EKC relationship, however the turning point for imports were higher than for exports. Zoundi (2017) on the other hand, investigated 25 selected African countries during the 1980-2012 period using panel cointegration analysis coupled with various robustness tests did not find significant evidence for an EKC relationship, they did however find further evidence that renewable energies has a negative effect on CO_2 emissions. Regarding Asian countries, Apergis & Ozturk (2015) looked at 14 between 1990-2011, and examined multiple variables such as population density, land industry shares of GDP and institutions and found evidence of an EKC relationship. Regarding Latin America and the Caribbean Zilio & Recalde (2011) looked at a modified EKC, the EEKC or Energy Environmental Kuznets Curve which puts aggregate energy consumption as the dependent (environmental degradation) variable. The authors examined a panel of 21 countries over the period 1970-2007 and by using a cointegration approach did not find evidence of the EEKC relationship. Meanwhile, Román-Collado & Morales-Carrión (2018) analysed Latin America specifically, and grouped 20 countries in smaller clusters by those similar in terms of growth and CO_2 emissions per capita. While not strictly an EKC study, the authors made a decomposition analysis (as suggested in section 2.2.1) of the driving forces behind CO_2 emission changes during the period 1990-2013, and found that the emissions doubled and the effects of population and economic activity were the biggest drivers of increased emissions, fossil fuel as part of the total energy supply as well as carbon intensity also functioned as driving forces of CO_2 emissions. The only decrease in emissions, as suggested by the authors' findings was changes in energy intensity, which declined over the time period.

The modern studies has shown that inference can be made using the Environmental Kuznets Curve as an analytical framework, capable of examining specific countries, regions as well as the impact of various variables. In addition there has been many attempts to statistically establish causation between emissions and economic growth, and the evidence suggest a bi-directional causality in the long and short-run.

Chapter 3

Empirical approach

3.1 Data

The variables used in this study are carbon dioxide (CO_2) which in the model specification will have the variable name PCCO2 and PPP-adjusted GDP per capita dubbed PCGDP. As mentioned earlier, there is a discussion about whether to use a local or global pollutant as the dependent variable, but local pollutants primarily have a local impact and can typically be reduced relatively cheaply (see section 2.1.2). CO_2 on the other hand, as a global pollutant is generally considered as the greater long term global threat, and has become the focus of most literature, it will also be considered in this study. Some argue (again see section 2.1.2) that global pollutants are not always correctly attributed to a particular country, and as such this study uses a measure based on emissions. Similarly Gross Domestic Product (GDP) will be used apposed to another prosperity proxy (such as Gross National Income (GNI)) because we are interested in production within the countries. Furthermore the specific indicator will be both inflation adjusted (by being measured in relation to 2011 US dollars), and purchase power adjusted in order to account for living standards of the countries.

The data for the variables are sourced separately in order to utilize the best data available. Data on carbon dioxide emissions is based on the free material downloaded from the Gapminder website (Gapminder (n.d)). The data set contains information on CO_2 emissions from 194 countries over the years 1800-2018, and is measured as metric tonnes per capita. The data quality seems to increase over time and the coverage is sporadic until 1900, and improves greatly after 1960. GDP data is sourced via Bolt et. al (2018) from the Maddison project which provides information on long run economic development, featuring inflation adjustment, where the GDP is calculated in relation to 2011 U.S dollars, and an adjustment for purchasing power which enables accurate cross country comparisons. The data covers 169 countries over the period 1AD to 2016, but as the earliest data is estimated by extrapolation, the quality again increases over time. In addition the data set includes categories of continents and regions.

The data is divided into four groups of 14 developing countries by continents and regions as provided by Bolt et. al (2018), over the time period 1960-2016. The first group is Asia, containing information on southern and south-eastern Asian countries, the second is Latin America and the Caribbean and finally two African groups, which includes sub-Saharan countries divided in east and west. The reasoning behind these groupings is based on (Moreno & Trehan 1997), who found that neighbouring countries generally develops similarly and the analysis made by Román-Collado & Morales-Carrión (2018) which made comparisons between groups of Latin American countries of similar economic and environmental nature. The four regions were chosen as they represent countries that have developing potential from three different parts of the globe, however an argument can be made that the countries within the regions are not similar enough, looking at figure 3.1, this could be the case for Africa, hence separating the data into two regions, east and west. While the four regions might not be directly comparable, it is still interesting to see how different regions of developing countries tackle the issue of sustainability, as while there are differences between and within the regions, ultimately they all cause and face the same environmental problems so while there might not be one solution that fits all, there might be multiple solutions that fits some.

Figure 3.1 gives a basic overview of the countries used in the data sets and the CO_2-GDP relationship, the figure uses Loess or Locally Weighted Scatterplot Smoothing, which creates a smooth line between the observations of each country without assuming a particular distribution (Glen n.d.(1)), this might result in some information loss in favor of showing the general path of the countries development. In addition, logarithmic scale transformation was performed to increase the patterns readability. An important point which figure 3.1 highlights is how the within group variation seem to be less than the between group variation, the figure might also suggest potential results, as both the Asia and Latin America groups seem to go from bottom left to top right which could imply that the variables share the same long term trend. Visually, both African data sets seems less promising, as both data sets are less coherent in shape and direction.

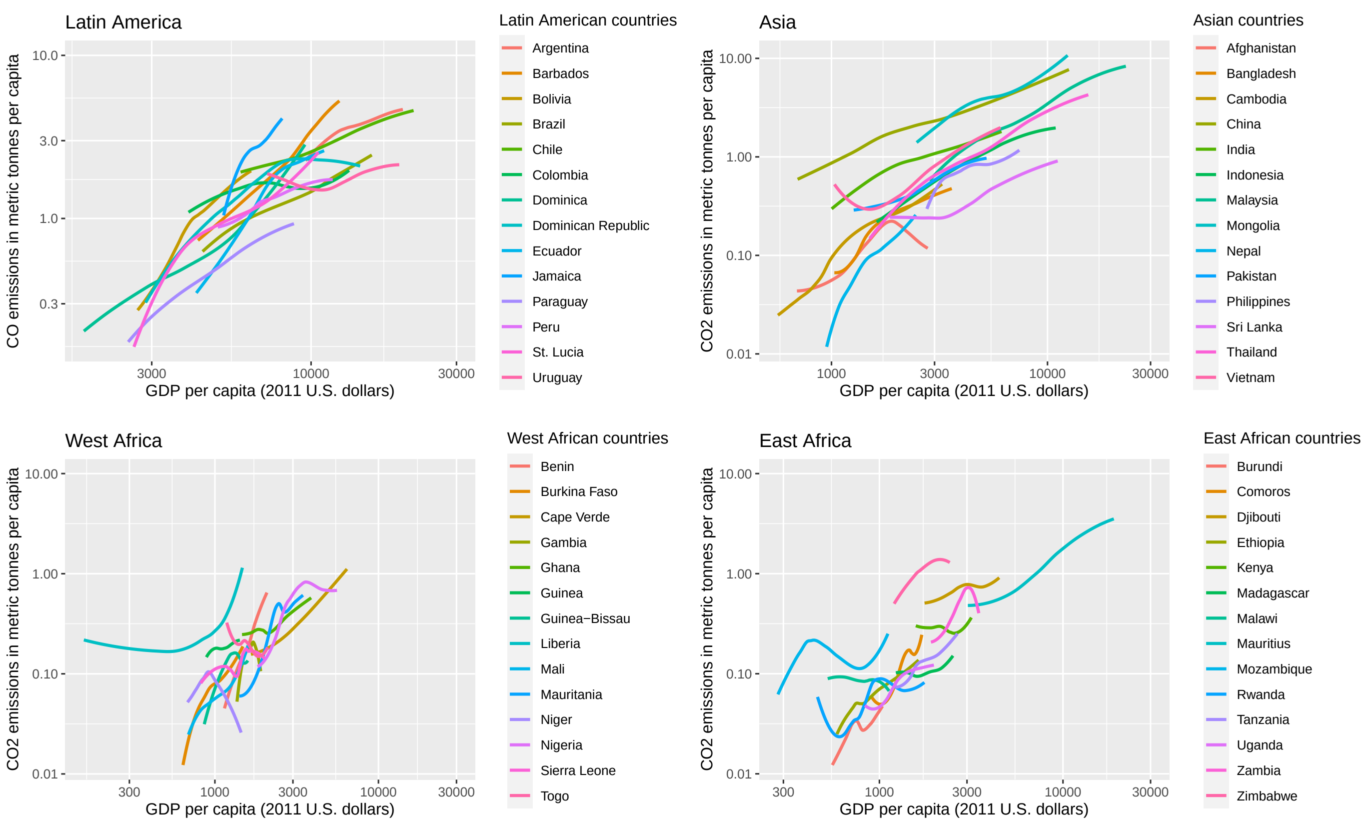

Figure 3.1: Carbon dioxide emissions per capita on GDP per capita in constant 2011 U.S dollar, for the four regions, employing logarithmic scale transformations for the axles and Loess time series smoothing. Visualization made by the author, data sources: Gapminder (n.d), Bolt et. al (2018).

3.2 Model and specification

The model used in this study is based on Grossman & Krueger (1991) with formalization adapted from Ahmad et.al (2021), where CO_2 emissions in million tonnes per capita is the environmental degradation proxy and inflation and purchase power adjusted Gross Domestic Product per capita is the prosperity proxy. The mathematical function can be expressed as

$$PCCO2 = F(PCGDP), \tag{3.1}$$

which is used to estimate a regions wealth's relation to carbon dioxide emissions using the quadratic specification of the Environmental Kuznets Curve:

$$lnPCCO2_{it} = \beta_0 + \beta_1 lnPCGDP_{it} + \beta_2 ln(PCGDP)^2_{it} + \delta_i + \delta_t + \varepsilon_{it}. \tag{3.2}$$

Where $lnPCCO2_{it}$ is the natural logarithm of carbon dioxide per capita, β_1 and β_2 is the coefficient of the natural logarithm of GDP and GDP^2 respectively. δ_i is a dummy variable for the individual country and δ_t is the dummy variable for time in years. ε_{it} is the error term. EKC conditions are satisfied if $\beta_1 > 0$ and $\beta_2 < 0$, which results in an inverse U-shape and the turning point is defined as $\mu = \frac{-\beta_1}{2\beta_2}$. The reason for transforming the variables into natural logarithms is, to be able to represent the estimated parameters as long-run elasticises according to Ahmad et. al (2021). This means that we could interpret them as that X% increase in PCGDP is associated with a Y% increase in PCCO2.

Regarding choice of control variables as discussed in section 2.1.2, it is a balance of omitted variable bias (bias caused by unobserved variables) and misspecification (bias caused by including irrelevant variables). This study has chosen not to include control variables, not only because of the risk of misspecification, but also because of the difficulty of acquiring data on any control variable of meaningful value with adequate coverage and quality over the time period and countries chosen. In addition, this makes the analysis more general in order to compare the region more fairly. This reasoning is in line with previous research where studies have had to choose between having a longer time frame, including more variables and a larger number of countries to be included in the analyses (Cole et. al 1997; Shahbaz et. al 2013; Apergis 2016).

As a way of counteracting some of the potential omitted variable bias, the parameters of the Environmental Kuznets Curve will be examined using the panel fixed effects, or "within" estimator using the "plm"- package by Croissant & Millo (2008) in R. The fixed effects model, together with the random effects model is usually referred to as a mixed model, in order to test whether to use one or the other, a Hausman specification test can be employed (Glen n.d.(2)). The intuition behind the fixed effects estimator is to run separate ordinary least squares (OLS) regressions while holding some effects constant or "fixed" in order to account for unobserved heterogeneity (variation) across entities and time. Holding between countries effects fixed, we can account for the variation existing across the countries but are constant over time, which enables us to tackle the problem of cross-sectional variation. In a similar way by holding the time effects, it allows us to account for unobserved heterogeneity that are constant over countries but varies over time. By using both individual and time effects we can combat potential omitted variable bias in both the cross-sectional and the time series aspect of our panel (Hanck et. al 2021). The random model works in a similar fashion, but assumes that the variation between countries has its own variation according to some estimated distribution (Midway 2022).

In addition, this study will run a unit root test, to determine if the time series are stationary (Lau et. al 2019), as well as a cointegration test (Pedroni 1999, 2004) in order to examine the variables long term trend relation, which has the added benefit of making sure that our estimated parameters are consistent (Vogelsang & Wagner 2014). Furthermore, Granger-causality will be tested, using the test developed by Dumitrescu & Hurlin (2012) in order to gain deeper understanding of the relationship between the variables. A limitation of the methodology is that it does not take cross sectional dependency, or short term between country correlation caused by common shocks into account. Some issues arising from this might be counteracted by including the time fixed effects estimator however.

3.3 Diagnostics

This section is made up of two parts of diagnostic test of the variables and time series of all countries included in the data. Section 3.3.1 performs unit root and cointegration tests, and section 3.3.2 performs a Granger-causality test.

3.3.1 Unit roots and cointegration

To test for potential unit roots, the four tests as suggested by Lau et. al (2019) are performed, the null hypothesis of the tests is the presence of an unit root. The test results in table 3.1 implies that we cannot reject the null, which suggests the presence of a unit root in the variables. From this we can infer that the variables are non-stationary which could result in spurious regression results. However, according to Vogelsang & Wagner (2014), if the series are cointegrated, OLS (which the fixed effects model is a form of) will still be consistent.

Test	CO_{pc}^2	GDP_{pc}	GDP_{pc}^2
Levin, Lin & Chu	5.139	26.546	28.131
Lm, Pearsan and Shin W-stat	21.544	6.985	23.092
ADF-Fisher χ^2	175.899	76.650	70.689
PP-Fisher χ^2	163.862	72.094	60.966
Note:	*p<0.1; **p<0.05; ***p<0.01		

Table 3.1: Panel unit root tests on the variables, note: only the Levin, Lin & Chu test assumes a common unit root process, the others assumes an individual unit root process.

The Panel Pedroni residual cointegration test as created by Pedroni (1999, 2004), can be performed in order to determine whether or not the time series included in the panel are cointegrated. The purpose of performing these tests is twofold, firstly because it tells us that there is a long-run trend between the variables and that OLS will be consistent. The null hypothesis of the test are that the time series are not cointegrated, and according to the various test statistics in table 3.2, we can reject the null. Lau et. al (2019) argues that panels where N is large in relation to T, the weighted statistic should primarily be considered. And since this study fulfills criterion (N = 798 observations and T = 58 time periods), we have evidence of cointegration as all test except the panel ν rejects the null at 99% at least. Thus this study will assume cointegration going forth.

3.3.2 Granger-causality

The Granger-causality test, as developed by Dumitrescu & Hurlin (2012), based on Granger (1969) can be performed in order to test for causality between the variables. Where the null hypothesis is that Y does not Granger cause X for all individuals and the alternative hypothesis is Granger causality for at least one individual. The test result suggest Granger-causality in both directions with significant evidence at 1 lag length. Note however that Granger-causality is a rather weak definition of causality, as given by the hypotheses, which means that the results tell us that there is not, non-causality between the variables.

Test	Statistic	Weighted Statistic
Panel ν	7.683^{***}	0.264
Panel ρ	-5.348^{***}	-6.125^{***}
Panel PP	-5.253^{***}	-6.778^{***}
Panel ADF	-8.139^{***}	-5.734^{***}
Group ρ	-2.885^{***}	
Group PP	-4.931^{***}	
Group ADF	-3.050^{***}	
Note:	*p<0.1; **p<0.05; ***p<0.01	

Table 3.2: Panel Pedroni residual cointegration test between the series CO^2_{pc}, GDP_{pc} and GDP^2_{pc} with a residual lag length of 1.

Model	Lags	$\tilde{Z}$
$GDP_{pc} \Rightarrow CO^2_{pc}$	1	12.852^{***}
$CO^2_{pc} \Rightarrow GDP_{pc}$	1	154.82^{***}
Note:	*p<0.1; **p<0.05; ***p<0.01	

Table 3.3: Output from the Dumitrescu & Hurlin Granger (Non-)causality test

Chapter 4

Analysis

4.1 Results

This section contains the results and implications of the Hausman test in section 4.1.1 and section 4.1.2 accounts for the results of the panel fixed effects estimator run on the four data sets.

4.1.1 Hausman test

A Hausman test can be used in order to determine if the random effects or fixed effects estimator should be used. The test checks if any of the unique errors are correlated with the explanatory variables (Glen n.d.(2)). The zero hypothesis of this test is result is that the both models are consistent and the alternative is that one (the random estimator) is inconsistent. The p values suggest that for Asia, Latin America and West Africa, we can reject the null hypothesis at a significance level of 99.9%, which implies that only the fixed effects estimator will be consistent. For the East African data set on the other hand, we can only reject the null at the 90% significance level, which mean that the random effects estimator could be consistent. Therefore, the fixed effects estimator will be used for the Asia, Latin America and West Africa data sets, while the random effects estimator will also be used for the East Africa data set.

4.1.2 Regression

A feature of the Environmental Kuznets Curve is the ability to calculate a turning point, or the point in a country or regions development, where the rate of environmental degradation starts to decline (as discussed in section 2.2.1). This turning point can be calculated from the estimated coefficients with rather simple mathematics but, especially in the case of developing countries, the value of the calculated turning point has been criticized (Richmond & Kaufman 2006), and as it enters the realm of foresight and prediction (Pearson 1994) it can be misleading. The turning points of the four regions are therefore calculated and presented in the appendix (chapter 4). Tables[1] 4.2-4.5 show the output of the fixed effects estimator on the the four data sets, while table 6.4 (appendix) show the output of the random effects estimator on the East Africa data set. The main points of interest of the tables are the individual and time, two-ways effects, which are the coefficients estimated using the combined model, as well as the adjusted R^2 value which estimates how much of the variance in the model that is explain by the regression (this values ranges from 0-1).

The results from the estimator run on the Asia data set (table 4.2) found evidence of the inverted U-shaped Environmental Kuznets Curve in the region, which is in line with previous research. However while the result is qualitatively what could be expected, the estimated coefficients however lose statistical significance due to large standard errors, in particular for the second polynomial GDP variable. The coefficients suggests that an increase in per capita GDP of 1% corresponds with an increase in carbon dioxide emission per capita of 2.5%, which is only significant on a 10% level, while an 1% increase in GDP per capita squared pushes the emissions down by 0.104% is statistically insignificant. We can also see that the result differ when controlling for unobserved variables that varies over time but not countries and when doing the same for variation across countries but not time, meaning that we might have eliminated some omitted variable bias.

On the other hand the results from the Latin American data set (table 4.3) show significant evidence of the Environmental Kuznets Curves inverted U-shape, which deviates from the established literature. Interestingly, the slope of the Latin America curve is

[1] The tables were created using the "Stargazer" package courtesy of Hlavac (2018) which converts regression results created in R into code for LaTeX-tables.

	Asia	Latin America	West Africa	East Africa
χ^2	87.853	54.812	26.277	4.743*
df	2	2	2	2
Note:			*p<0.1; **p<0.05; ***p<0.01	

Table 4.1: Result of the Hausman test.

	Dependent variable:		
	lnPCCO2		
	Individual effects	Time effects	Individual and time effects
lnGDPPC	2.845**	3.035	2.501*
Standard Error	(1.381)	(1.891)	(1.288)
$lnGDPPC^2$	−0.103	−0.090	−0.104
Standard Error	(0.082)	(0.107)	(0.082)
Observations	798	798	798
R^2	0.743	0.606	0.345
Adjusted R^2	0.738	0.575	0.281
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 4.2: Fixed effects regression output from the Asia data set.

much steeper than the Asia data set, and the effect of an 1% increase of income per capita corresponds to a 9% increase in emissions per capita. In addition there was little change between the estimated coefficients when looking at individual, time or both effects. At the same time, the Latin American data set enjoys the highest adjusted R^2 values.

Finally, the results of the regressions both African data sets did not find evidence of the inverted U-shaped EKC, which could be expected as previous research has found mixed results. Instead as observed in table 4.4 regarding the West African data set, when only looking at individual effects, there are significant evidence (at 5 and 1% levels respectively) of what could be describes as an U-shaped EKC, where a 1% increase in GDP per capita relates to a 2.2% decease in emissions per capita and a 1% increase in GDP^2 per capita corresponds to an 0.2% increase in emissions per capita. However significance is lost as time effects are included. The East African data set, covered in tables 4.5-6 only find significant effect on a positive relationship between the squared variable and the environmental degradation variable in both of the fixed and random effects models. Both the western and eastern African data set generally has the lowest adjusted R^2 values.

	Dependent variable:		
	lnPCCO2		
	Individual effects	Time effects	Individual and time effects
lnGDPPC	8.900***	8.798***	9.180***
Standard Error	(1.956)	(2.953)	(1.779)
$lnGDPPC^2$	−0.437***	−0.425**	−0.471***
Standard Error	(0.111)	(0.170)	(0.101)
Observations	798	798	798
R^2	0.784	0.631	0.485
Adjusted R^2	0.779	0.602	0.435
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 4.3: Fixed effects regression output from the Latin America data set.

4.2 Discussion

The two parts of this section contains the discussion of the results estimated by the panel fixed effects model from section 4.1 in relation to the mechanisms of the Environmental Kuznets Curve from section 2.1.1 and previous research from section 2.2.2. Also included is and a discussion on the results of the Granger-causality test in relation to other causality studies from section 2.2.2 and its wider implications for the Environmental Kuznets Curve theory and the results of this study.

4.2.1 Estimation results and the Environmental Kuznets Curve

The result of the regressions were mixed, and the only region where significant evidence of the Environmental Kuznets Curve were found in the Latin American data set. The coefficients of the Asia data set also fulfilled the conditions of the inverted U-shaped, however only the first polynomial GDP per capita had a significant effect on emissions. For both the Africa data sets, the only significant effects were a positive relationship between GDP per capita squared and increased emissions. In this section, these results will be discussed in relation to the mechanisms of the Environmental Kuznets Curve and previous research.

Previous research has found evidence of the Environmental Kuznets Curve relationship

	Dependent variable:		
	lnPCCO2		
	Individual effects	Time effects	Individual and time effects
lnGDPPC	-2.265^{**}	-3.157	-0.636
Standard Error	(1.041)	(2.601)	(0.970)
$lnGDPPC^2$	0.240^{***}	0.290^{*}	0.108
Standard Error	(0.070)	(0.168)	(0.075)
Observations	798	798	798
R^2	0.337	0.466	0.266
Adjusted R^2	0.324	0.425	0.195
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 4.4: Fixed effects regression output from the West Africa data set

in Asia, Apergis & Ozturk (2015) used a data set of similar size to this study, but with a narrower time frame only considering the years 1990-2011. This time frame could have been a factor in the differing results, as it could have covered a period in which emissions declined in the region, it did also enable the authors to include more variables which could serve to improve the specification of the model. With the only significant effect (at the 10% level) of the results in table 4.4 being the one of GDP per capita, it could suggest that the region as whole experiences the scale effects of the Environmental Kuznets Curve, which is in line which the general expansion of Asian economies over the recent decades. As there were not any significant results of declining emissions in the Asia data set, this could be interpreted as the absence of composition effects, or that composition effects in other regions place an environmental strain on Asia. But on the other hand composition and technique effects as described by figure 2.1 does not necessarily have to follow chronologically, and as such these effects could instead manifest in the slope of the curve. Relating the slopes to the scenarios as presented in figure 2.2, given that the coefficients estimated are more similar to the African data sets, and considerably lower than the Latin American data set, which could suggest either the conventional scenario, or a *revised EKC* scenario where technique effects have enabled some form of decoupling.

In the Latin American data set, the fixed effects model found statistically significant evidence of the inverted U-shaped Environmental Kuznets Curve. When compared to the Asian data set, the the initial slope is considerably steeper. Earlier in the study, two

	Dependent variable:		
	lnPCCO2		
	Individual effects	Time effects	Individual and time effects
lnGDPPC	−0.783	−0.792	−0.986
Standard Error	(0.899)	(3.476)	(0.895)
$lnGDPPC^2$	0.115**	0.138	0.127**
Standard Error	(0.052)	(0.218)	(0.051)
Observations	798	798	798
R^2	0.342	0.570	0.309
Adjusted R^2	0.329	0.536	0.242
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 4.5: Fixed effects regression output from the East Africa data set

previous empirical studies on Latin America in this context were mentioned. The first one, Zilio & Recalde (2011) looked a modified version of the Environmental Kuznets Curve, which places energy consumption as the dependent variable, and the authors did not find significant evidence for that relationship. However their result does not necessarily contradict the findings made in this study, since it could reflect changes in carbon intensity which means that less carbon were emitted per unit of electricity used. This could indicate that technique effects are in play. The second study was by Román-Collado & Morales-Carrión (2018) who did not preform an Environmental Kuznets Curve analysis, instead they decomposed the driving factors of carbon dioxide emissions changes in the Latin American context and found that only the decrease in energy intensity, or the ratio between energy consumption and GDP had a negative effect on emissions in the region over the time period. Which deviates from the model estimations made in this study and could highlight the problems of specification when modelling the Environmental Kuznets Curve. Regarding figure 2.2, as mentioned in the previous paragraph, the estimated coefficients place the Latin American data set at the steepest upward curve in this study, which could represent either the *New Toxics* scenario, where new pollutants continuously deprecates the environment or the conventional scenario, however this is again inconclusive since this study found no third scenario in the results.

Regarding the result of the regression runs on both the Africa data sets, only showed significant evidence of a potential positive relationship between GDP per capita squared and carbon dioxide emissions per capita (on a 99% level for the West Africa data set only considering individual effects, and on a 5% level for the East African data set considering both effects). Since the previous researched discussed in section 2.2.2, had differing results, this could be expected. As Boutabba et. al (2018) found evidence of the Environmental Kuznets Curve when examining a data set of similar cross-sectional size but on a lesser time frame. Furthermore, the study also discussed the role of trade in intermediate goods, and found that in relation to exporting primary goods, engaging in a more fragmented production processes could mitigate CO_2 emissions. In contrast, Zoundi (2017) did not find significant evidence of an EKC relationship when looking at a larger sample, both in terms of countries and time period included. The authors did however emphasize the role of renewable energy production in the region, which they found would reduce CO_2 emissions. Considering the level of economic development, one could argue that the U-shaped result could constitute a preliminary phase before an eventual upward trend of emissions as GDP increases (scale effects). This could imply that the Environmental Kuznets Curve might be dependent on level of economic development contrary to the evidence of Biligi et. al (2016). Regarding the composition effects, the theory states that pollution intensive production will move to the location with the least environmental regulation, the theory also presumes that these regulations will spawn from a willingness to pay for a cleaner environment at a certain point of prosperity. Hence an argument could be made that if Africa (for instance) remains the least developed region, it risk becoming a global pollution haven. The results of the estimations made by this study impede the ability to relate the regions in relation to figure 2.2, as the suggested U-shaped does not include the first bend depicted. On the other hand, this study found evidence of increasing emissions in relation to GDP squared, which could foretell a scenario of greater environmental impact than the worst scenario proposed by Dasgupta et. al (2002).

4.2.2 Causality

Granger-causality is a common method of estimating causal relations and directions between variables, and have become a staple in Environmental Kuznets Curve studies. The reason for including a causal element in the studies is to attempt to untangle effects in a complex process of sustainable development. The results of this study suggest an bi-directional causal relationship between carbon dioxide emissions per capita and GDP per capita, which is in line with previous research (Shahbaz et. al 2013; Lau et. al 2014), with some having found additional variables with causal relation such as energy consumption

(Ahmad et.al 2021).

The multi-directional causality links has the implication that environmental degradation and economic activity exists in a potential feedback loop where both could continually increase indefinitely. This highlights the dangers of accepting the Environmental Kuznets Curve at face value, and presuming an automatic environmental improvement at a certain point of economic development. Possible solutions exists, such as a shift in energy intensity, where less energy is required per unit of GDP, but as previously discussed a potential decoupling measured in GDP could distort the apparent relationship as production becomes cheaper while services more expensive. More important could improvements carbon intensity be where less carbon is emitted per unit of energy spent, which emphasizes the need of renewable energy production in order to break the feedback loop between carbon emissions and economic growth.

4.3 Conclusion

This study has been examined the Environmental Kuznets Curve, its mechanisms, problems and shortcomings, history and its relationship to four regions of developing countries using the panel fixed effects model. In addition a tangential causality analysis was performed on the panel wide data. The results found significant evidence of an inverted U-EKC relationship in Latin America and the Caribbean, weaker evidence of such a relationship in south and south-eastern Asia, and finally evidence of a possible U-shaped relationship in both west and east Africa. Thus we can conclude that there are differences in environmental degradation as different regions develop, and these differences might be due to scale effects as economic development increases, composition effects when the regions engage in trade and technological effects as regions transition to renewable energy sources. We can also conclude that two out of the four regions can be described by the inverted U-shape of the Environmental Kuznets Curve. Lastly we conclude that there might be a bi-directional causality relation between CO^2 emissons per capita and PPP-adjusted real GDP per capita.

This study's findings is limited by certain statistical qualities such as cross-sectional dependencies and estimators robust when cross-sectional dependencies are in effect, and in terms of specification as no additional control variables were used. A major drawback of modelling the Environmental Kuznets Curve is the wide possibilities of specifying it, in order to attain the most accurate results, which inhibits the potential to compare the findings of different research. As such, future research could benefit by conducting standardized analysis both on a narrower and broader scope of included countries and regions. Possible policy suggestions would be, investments into less carbon intensive energy production in order to counteract the adverse environmental effects of economic growth stemming from the causal relationship between the variables, and stricter regulation in developing countries has to be adopted earlier in order to prevent regions from remaining in a position of pollution havens.

Chapter 5

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Chapter 6

Appendix

6.1 Distribution of the data sets

Table 6.1 provides some descriptive statistics and shows the levels of yearly emissions (note the difference in maximum emission between the Asia data set and the west Africa data set).

	Asia		Latin America		West Africa		East Africa	
	PCCO2	PCGDP	PCCO2	PCGDP	PCCO2	PCGDP	PCCO2	PCGDP
Min. :	0.004	565	0.160	1796	0.008	4158	0.011	280
1st Qu.:	0.227	1411	0.971	5334	0.098	1137	0.071	862
Median :	0.563	2652	1.630	7325	0.183	1438	0.127	1464
Mean :	1.208	3801	1.831	8033	0.251	1699	0.360	2027
3rd Qu.:	1.390	4566	2.320	10138	0.300	1953	0.367	2291
Max. :	15.100	23053	5.760	21696	1.730	6418	3.450	18918

Table 6.1: Distribution of the data sets, note that due to the panel data structure, the minimum value may come from the earliest date.

6.2 Turning point

The hypothetical turning point can be calculated by optimising the function given by the coefficient estimates. As only the Asia and Latin America data sets coefficients fulfilled the EKC-conditions, $\beta 1 > 0$ and $\beta 2 < 0$, with only the latter showing significant results, only those turning points will be calculated, using the formula

$$\mu = \frac{-\beta_1}{2\beta_2}, \tag{6.1}$$

Which is displayed in table 6.2. The results show that the turning point for a given country in Latin America is 17k (2011 U.S. dollars) per capita, and 166k (2011 U.S. dollars) for any given Asian country, which when referring to table 6.1 is far out of sample for Asia, but not for Latin America. Some researches however Boutabba et. al (2018) has used the turning point as an indicator when comparing different effects.

Latin America		Asia	
lnPCGDP	PCGDP	lnPCGDP	PCGDP
9.745	17k (2011 U.S. dollars)	12.024	166k (2011 U.S. dollars)

Table 6.2: Calculated hypothetical turning points.

6.3 Random effects model on the East Africa data set

Table 6.3 displays the regression output from the random effects model on the East Africa data set. The estimated coefficients were similar to the fixed effects model, but included the estimated slope which in this context is not very useful. Table 6.4 however tells us that over 80% of the variation comes from individual effects.

	Dependent variable:		
	Y		
	Individual effects	Time effects	Individual and time effects
lnGDPPC	−0.765	−0.763	−0.765
Standard Error	(0.922)	(3.493)	(0.923)
$lnGDPPC^2$	0.114	0.135	0.114^{**}
Standard Error	(0.053)	(0.220)	(0.053)
Slope	-2.350^{**}	−3.500	−2.352
Standard Error	(3.948)	(13.691)	(3.950)
Observations	798	798	798
R^2	0.347	0.570	0.347
Adjusted R^2	0.346	0.569	0.346
Note:			$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 6.3: Random effects regression output from the East African data set

Effects	*var*	*std.dev*	*share*
Idiosyncratic	0.147	0.3836	0.192
Individual	0.620	0.7879	0.808
Time	0	0	0

Table 6.4: Random effects estimation